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Integrating Sustainability in Green H_2 Advancements for Pakistan:

An EESG Perpective

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Contents

List of Figures

List of Exhibits

List of Tables

List of Boxes

Abbreviations

B	Billion
CAPEX	Capital Expenditure
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization, and Storage
CO2	Carbon Dioxide
CfD	Contracts for Difference
EU	European Union
ESG	Environment, Social, Governance
EESG	Environment, Social, Governance and Economy
EMDEs	Emerging and Developing Economies
EC	European Commission
ETS	Emission Trading Scheme
EHB	European Hydrogen Bank
GHG	Greenhouse Gas
GW	Gigawatt
GO	Guarantee of Origin
H2	Hydrogen
HAR	Hydrogen Allocation Rounds
ISO	International Organization for Standardization
IRENA	International Renewable Energy Agency
IEA	International Energy Agency
Kg	Kilogram
KPIs	Key Performance Indicators
LCOE	Levelized Costs of Energy
LCOH	Levelized Costs of Hydrogen
M	Million
MDBs	Multilateral Development Banks
Mt	Million Tons
MW	Megawatt
MWh	Megawatt Hour
NDCs	Nationally Determined Contributions
NREL	National Renewable Energy Laboratory
O&M	Operations and Maintenance
OPEX	Operations Expenses
PPA	Power Purchase Agreement
PPP	Public-Private Partnership
PtX	Power-to-X
R&D	Research and Development
RE	Renewable Energy
SDGs	Sustainable Development Goals
SMR	Steam Methane Reforming
SLO	Social License to Operate
Gt	Gigatons
NIMBY	Not in My Backyard
LCA's	Life Cycle Assessments
WBCSD	World Business Council for Sustainable Development
H2NZ	Hydrogen for Net-Zero
VCM	Voluntary Carbon Market
BCC	Blue Carbon Credits
ITCs	Investment Tax Credits
IRA	Inflation Reduction Act
PTC	Production Tax Credits

Glossary

Biodiversity

Biodiversity refers to the variability of life on Earth, including the diversity of species and ecosystems.

Brine

Brine, or briny water, is water with a high concentration of salt, usually sodium chloride. It is also a by-product of various industrial processes, like desalination, and needs wastewater treatment for proper disposal.

Carbon Capture Utilization and Storage (CCS/CCUS)

It is an umbrella of emerging technologies to capture carbon dioxide at the point source of carbon emissions specifically in hard-to-decarbonize industries. This captured carbon can then be stored in selected underground repositories and later could be utilized to make commercially marketable products.

Contracts for Difference (CfD)

CfDs are financial agreements that guarantee a fixed price for electricity generated by renewable projects. If market prices fall below this fixed price, developers receive a payment to cover the difference; if prices exceed it, they repay the excess. CfDs provide revenue stability, encouraging investment in low-carbon technologies.

Desalination

It is the process of removing salt and other impurities from seawater or brackish water to produce fresh water. It is used to provide drinking water in areas where natural water sources are scarce or contaminated.

Doing Business Index

The Doing Business Index is a World Bank metric that evaluates the ease of conducting business in various countries. It considers parameters such as obtaining permits, registering property, and enforcing contracts, providing a comparative measure of the regulatory environment's impact on business operations.

Downstream cooling processes

Downstream cooling processes refer to cooling techniques used in the later stages of industrial or chemical processes to lower the temperature. They can involve various methods such as refrigeration, heat exchangers, or cooling towers.

EESG framework (Economic, Environmental, Social & Governance Framework)

The International PtX Hub has created an EESG Framework for Hydrogen and PtX, incorporating the key areas of Environmental, Social, Governance, and an additional Economic dimension to guarantee comprehensive sustainability. Implementing this framework, setting PtX sustainability standards, and developing corresponding certification schemes are vital responsibilities for all stakeholders, and key to establishing clear national policies and international agreements.

Electrolysis

It is the process of splitting water into hydrogen and oxygen by inducing electricity. Green electrolysis is the one carried out by renewable energy.

Emerging and Developing Economies (EMDEs)-

These are countries transitioning from low to middle income, characterized by rapid growth and development. They often face challenges like lower industrialization and infrastructure levels but are important due to their expanding markets and investment potential

Emission Trading Scheme (ETS)-

An ETS caps total emissions and allows companies to buy and sell emission permits. It incentivizes emission reductions by letting firms trade allowances, aiming for cost-effective overall emission reductions.

Environmental Scale

This scale assesses the quality and sustainability of a country's environmental practices. It evaluates factors like air and water quality, waste management, natural resource use, and overall environmental impact to gauge environmental health and sustainability.

Environmental, Social, and Governance (ESG)-

This criterion is increasingly utilized by investors to evaluate risks and opportunities associated with sustainability and ethical practices within companies and projects.

Front End Engineering Design (FEED)

FEED is the initial phase in project development involving detailed planning and design to define the project scope, costs, and feasibility. FEED helps in identifying potential risks, refining project specifications, and setting the foundation for detailed engineering, procurement, and construction phases.

Gini Coefficient

It is a measure of income inequality within a population, ranging from 0 (perfect equality) to 1 (perfect inequality). It quantifies the distribution of income or wealth, with a higher Gini coefficient indicating greater inequality.

Global Governance Scale

This scale evaluates the quality and effectiveness of governance across countries. It assesses factors such as political stability, rule of law, corruption, and government effectiveness to measure how well countries manage public affairs and uphold democratic principles.

Guarantee of Origin (GO)

GO is a certification that verifies the source of renewable energy, ensuring that electricity supplied to consumers is generated from renewable sources like wind, solar, or hydro. It provides transparency and helps track the environmental impact of energy consumption.

Hydrogen for Net-Zero (H2NZ)

The Hydrogen for Net Zero Initiative (H2NZ) is a distinctive platform that unites hydrogen industry experts and carbon market specialists. It operates with a collaborative, open, and transparent approach to achieving efficient and effective outcomes. The initiative is coordinated by the South Pole and Perspectives Climate Group, in partnership with Verra and the Gold Standard.

Inflation Reduction Act (IRA)

The Inflation Reduction Act (IRA) is a U.S. law aimed at reducing inflation through measures such as lowering prescription drug costs, investing in clean energy, and supporting climate initiatives. It also includes provisions for tax credits and incentives to drive economic growth and tackle climate change.

Investment Tax Credits (ITCs)

Investment Tax Credits (ITCs) are financial incentives provided by governments that allow businesses or individuals to reduce their tax liability by a percentage of their investment in certain eligible assets or projects, such as renewable energy installations. ITCs help lower the upfront cost of investments, encouraging the adoption of technologies and promoting economic growth in targeted sectors.

Just Energy Transition

This term refers to ensuring that energy transition is fair and equitable. It focuses on addressing social and economic impacts, providing support for affected workers and communities, and ensuring access to clean energy for all.

Levelized Cost of Electricity (LCOE)

It quantifies ($/kWh) the average present value of electricity generation expenses throughout the lifespan of a power plant.

Levelized Cost of Hydrogen (LCOH)

Like LCOE, it represents the hydrogen production over the lifetime of the power plant operation quantified in $/kg.

Life Cycle Assessments (LCAs)

LCAs are evaluations that analyze the environmental impacts of a product or process from its inception to disposal. LCAs consider all stages, including raw material extraction, production, use, and end-of-life, to assess the overall carbon footprint and identify risks.

Nationally Determined Contribution (NDCs)

These are climate action plans submitted by countries under the Paris Agreement (2015). They specify each country's commitments to reduce GHG emissions and adapt to climate change. NDCs are periodically updated to reflect on the commitments being made.

Net-Zero Scenarios

Net-Zero scenarios are models that outline pathways to balance GHG emissions with removals, guiding policy, investments, and strategic planning to meet climate goals effectively and sustainably.

NIMBYism (Not in My Back Yard)

It refers to a phenomenon where individuals or groups support certain developments or projects in general but oppose them when they are proposed near their own homes or local areas.

Political Stability Index

The Political Stability Index measures the likelihood of political instability or violence in a country. It assesses factors like government stability, conflict, and civil unrest to gauge the overall political risk.

Power-to-X (PtX)

Loops are created to reduce carbon emissions in industrial chemical processes. PtX involves converting renewable electricity into an energy carrier known as 'X,' usually green hydrogen, or its derivatives. The focus is on e-fuels like e-methanol, e-kerosene, and e-diesel.

Production Tax Credits (PTCs)

These are tax incentives that provide a per-unit tax credit for energy produced from eligible renewable sources, such as wind or solar power. They are designed to encourage the generation of clean energy by reducing the cost of production.

SDG Compass

The SDG Compass helps companies align their strategies and manage their impact on achieving the SDGs. It outlines five steps for maximizing their contribution: understanding the SDGs, setting priorities, establishing goals, integrating sustainability, and reporting.

Social License to Operate (SLO)

SLO is the term used for acceptance from local communities and other stakeholders for a company's activities or projects. Unlike government-issued formal regulatory licenses, an SLO is an informal, non-tangible agreement provided by the community and relevant stakeholders. It is important to get an SLO for projects to avoid any unforeseen delays.

Steam Methane Reforming (SMR)

It is a process used to produce hydrogen by reacting to methane (natural gas) with steam. The reaction generates hydrogen and carbon dioxide, making it a key method for large-scale grey hydrogen production.

Sustainable Development Goals (SDGs)

United Nations' 17 SDGs, which form part of the 2030 Agenda for Sustainable Development. These goals address global challenges related to environmental, social, and economic sustainability and are designed to promote prosperity while protecting the planet.

Voluntary Carbon Market (VCM)

This is a voluntary marketplace that enables businesses and individuals to purchase carbon offsets voluntarily to offset their greenhouse gas emissions. Participants use the VCM to invest in projects that reduce or remove carbon from the atmosphere, supporting sustainability goals and enhancing environmental responsibility beyond regulatory requirements.

Executive summary

The rapid transformation of the energy landscape, driven by the carbon emissions mitigation objectives outlined in the Paris Agreement considers green hydrogen as a critical enabler of this transition. In hard-to-abate sectors, green hydrogen stands out as one of the most versatile energy carriers addressing the decarbonization needs of multiple sectoral applications i.e., industry, shipping, aviation, and long-haul transportation.

Many developing countries have set ambitious green hydrogen targets to meet domestic energy needs and to capitalize on emerging trade opportunities. Pakistan also intends to follow this trajectory by developing its green hydrogen strategy eventually. However, the country's green hydrogen production targets and trade objectives must remain aligned with sustainability standards. Environmental, Social, and Governance (ESG) criteria is crucial to achieve this. Currently, various frameworks are already in place to guide projects and corporations in addressing these critical aspects of sustainability.

This report focuses on incorporating ESG considerations into the development of green hydrogen projects for Pakistan. It utilizes a framework developed by International PtX-Hub, which includes an additional Economic dimension, thus referred to as EESG. Green hydrogen is a nascent market, with discussions still in the initial stages, particularly in Pakistan's context. Hence understanding the future potential of innovative and emerging technologies for hydrogen remains crucial, while integrating EESG principles is vital for ensuring the broader and intended impact.

To effectively address Sustainable Development Goals (SDGs), ESG has become essential for responsible business practices, investments, and corporate governance. It emphasizes the importance of looking beyond mere financial success to adopt the triple bottom line approach—People, Planet, and Profit. The ESG framework provides a strategic approach towards inclusiveness, accountability, and more thorough risk management. Integrating ESG factors into operations can drive growth in a just and equitable manner contributing to global sustainability efforts and prosperity. While ESG is gaining momentum worldwide, Pakistan lags in adopting these practices.

In Pakistan, ESG is still in the initial stages of development as a concept and in terms of corporate governance priorities. The adherence to ESG principles is hindered by limited awareness of its importance and benefits, widespread misconceptions, and resistance to additional regulations. The lack of comprehensive regulatory guidance and a shortage of industry leaders also complicate effective ESG integration. To fully reap the benefits of ESG, it must be embedded into policies, plans and roadmaps aimed at targeting individual companies.

The decarbonization efforts via green hydrogen could only be addressed if ESG standards are announced within the policy framework. This report highlights a comprehensive national picture for evaluating the multifaceted impacts of developing green hydrogen initiatives. It could be a steppingstone in understanding the commercial viability, environmental footprint, social acceptance, and governance considerations. It offers insights into how green hydrogen projects can contribute to enhancing energy security and expediting economic growth while addressing political and social challenges. It can guide stakeholders in making informed decisions, drive investment, and support effective implementation strategies, thereby advancing the green hydrogen projects and supporting broader climate and sustainability goals.

The green hydrogen market could be pivotal in reaching Net-Zero targets and combating the climate crisis. As Pakistan progresses in its green hydrogen journey, the integration of ESG principles will be essential to ensure that projects are developed with sustainability and responsibility at their core. Adopting a forward-looking approach to sustainability challenges will amplify the effectiveness of these initiatives, securing a climate-neutral future for the country. The EESG framework emphasizes the significance of integrating products, people, and policies in global hydrogen developments.

Key Findings

The main findings of the report are summarized below.

Economics (E)

- Current hydrogen production is a highly carbon-emitting process, where green hydrogen projects could be developed as a key climate action and mitigation strategy, to accelerate the energy transition and drive economic growth in selective sectoral applications.
- Green hydrogen is anticipated to be a core of industrial decarbonization in commitment to the Net-Zero targets. In Pakistan's case, green ammonia would be the best use case.
- In the current national landscape, it can contribute to deffosilization by offering independence from import-based fuels and hence providing greater energy security.
- Pakistan could delve into hydrogen trade and explore opportunities to enhance regional cooperation, and technology transfer and promote innovation, especially within the Asian region.
- Localized production and manufacturing of hydrogen-related equipment can revamp the industrial sector further, driving additional economic growth.
- Green hydrogen and PtX developments should be included in public and private investment and funding schemes. Public-private partnerships could be leveraged to reduce investment uncertainty.
- Enabling an integrated infrastructure (electricity grid, energy storage and pipelines) will be crucial for a fully integrated hydrogen economy.

Environment (E)

- The electricity used for electrolysis should always be sourced from renewable and supplementary energy sources.
- The water needs for green electrolysis are comparable to those of the Steam Methane Reforming process and significantly lower than those for coal gasification.
- The use of water resources should not exacerbate regional water stress. The addition of water desalination plants can provide co-benefits for the local community. However, environmental impact assessment should be carried out to ensure water sustainability.
- The cost of desalination is often overstated; it accounts for less than 2% of the total capital expenditure of the green hydrogen project.
- Brine waste should be disposed of properly, and international regulations should be established to govern this process.
- Green electrolysis requires less land than other energy resources; however, site selection should avoid areas that could significantly impact biodiversity.

Social (S)

- Developing hydrogen projects with additional renewable energy could be rendered a co-benefit to combat electricity poverty.
- Protection of cultural heritage and traditionally sacred places must be considered while approving project sites.
- Pakistan's hydrogen potential is situated in highly remote regions, where local communities could be fully involved, and the potential for local job creation could be maximized.
- A Social License to Operate (SLO) is important in ensuring the social acceptance of projects to avoid any unforeseen delays.
- Support should be provided for the transition from fossils to renewable industries, including reskilling and training.
- Human rights and basic labor standards must be upheld throughout the value chain.
- Social concerns and grievances should have proper mechanisms to be integrated into sustainability assessments in the planning phase to avoid any monetary loss.

Governance(G)

- Pakistan could implement clear and concise policies to integrate green hydrogen and climate strategies for achieving Net-Zero targets and Nationally Determined Commitments (NDCs).
- Socio-political instabilities can be addressed by developing and implementing frameworks incorporating innovative mechanisms to address the challenges.
- Multistakeholder dialogues and engagement are essential to creating an inclusive, bottom-up approach for implementable policies and roadmaps.
- An effective regulatory and legislative framework could be crucial to attracting a wide range of investment opportunities.
- The government could engage in international and bilateral agreements by providing clear financial benefits i.e., Incentivization or subsidies.
- In the initial stages of development, government-backed certification and standardization could be developed to ensure transparency and sustainability across all dimensions of the green hydrogen value chain.

Introduction

Hydrogen stands as a transformative energy vector capable of accelerating the global shift towards decarbonization. It is the missing puzzle in green industrialization that can create multiple avenues in job creation and drive economic growth, particularly in Emerging Markets and Developing Economies (EMDEs). By capitalizing on green hydrogen's potential to decarbonize multiple sectoral applications, industries can see a transition away from fossil fuel-based processes towards a sustainable future. The shift not only mitigates climate change but also catalyzes the development of new economic avenues centered around green hydrogen and its derivatives.

By 2050, green hydrogen is expected to reduce 85 gigatons (Gt) of CO_2 emissions in the industrial segment. While there is currently no established global market for green hydrogen, renewables-based hydrogen capacity is expected to grow to 600 million tons by 2050 [1]. To address green hydrogen needs, the number of countries with national hydrogen roadmaps have tripled in the past two years, indicating a strategic approach to capitalize on its potential economic benefits and the associated advantage of being an early mover.

Around USD 2.3 trillion (T) has already been allocated for the green transition. However, this amount represents only about 2% of the estimated capital needed to support the overall transition of hydrogen industry by 2050 [1]. For green hydrogen scalability, it remains crucial to develop appropriate legislative frameworks and accompanying international cooperation mechanisms.

The market liquidity of green hydrogen development is infused in the interplay between decarbonization and economic uplifting. It is anticipated that developing countries could potentially achieve a USD 1.4 T market by 2050, where over 65% of the market share will be situated in EMDEs [2].

Figure - 1 illustrates the global distribution of the Levelized Cost of Hydrogen LCOH ($/kg), highlighting the low-cost opportunities in developing regions. This presents a promising prospect for developing nations to capitalize on the economic turnover of hydrogen for equitable development. This development requires to be grounded in sustainability dimensions of green hydrogen projects, given the complex injustices that have historically accompanied energy development [3].

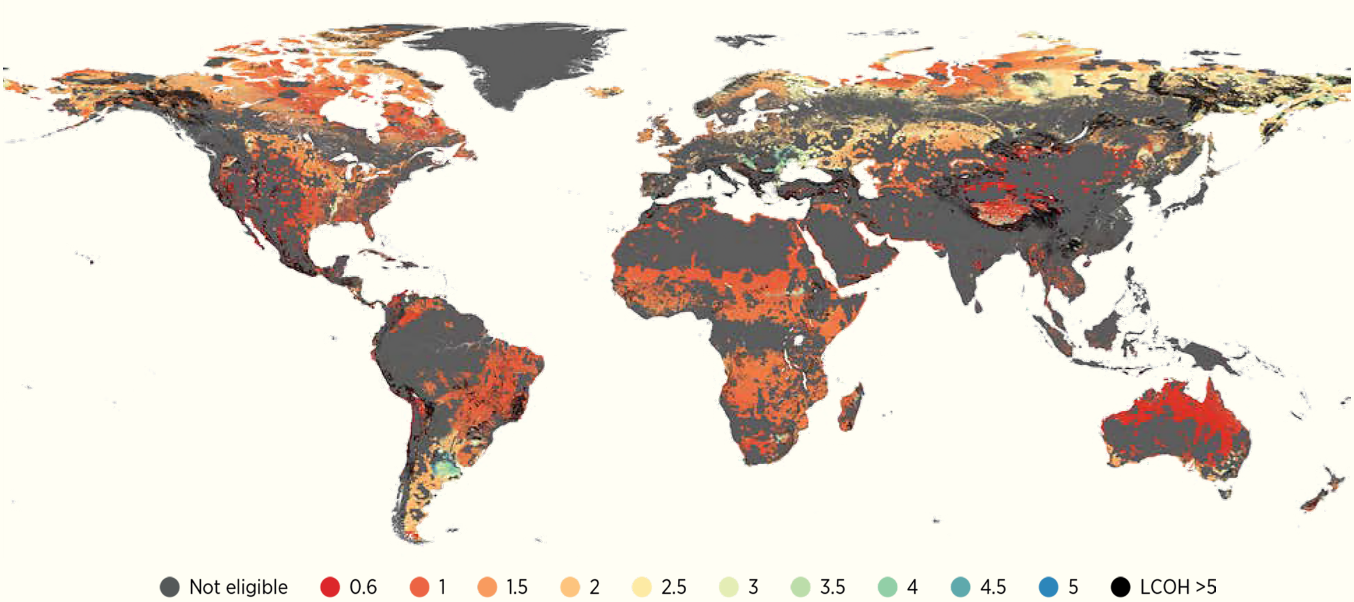


Figure - 1: Global distribution of Levelized Cost of Hydrogen (LCOH $/kg)-IRENA

Pakistan does have the potential to utilize its renewable energy (RE) resources to achieve a favorable LCOH of less than 2.00 $/kg by 2050 [4]. Advancing a green hydrogen economy could lead to green industrialization and support Pakistan's Net-Zero goals. Additionally, it presents an opportunity for interregional trade, with Pakistan's strategic position making it an ideal option for meeting the clean hydrogen needs of the Asian region.

Box - 1 Decarbonizing hard to abate sectors and green hydrogen possibility in Pakistan

Green hydrogen production will play a huge role in reducing carbon emission in many sectoral applications. Global hydrogen demand is mainly driven by ammonia production (60%), methanol synthesis (30%), the steel industry (4%), and other applications (6%) [13].For hard to decarbonize sectors, hydrogen and its derivatives are used as feedstocks, such as ammonia for fertilizers, methanol, and hydrogen peroxide. In the steel industry, hydrogen serves as a reducing agent in the primary iron extraction process. In refineries, hydrogen plays a crucial role in hydro treating processes, which are used to remove sulfur from fossil fuels through desulfurization.

Hydrogen's versatile usage can lead to uncertainty, but its most effective decarbonization opportunity depends on the national context. Important considerations include the country's demand needs, market development, and specific decarbonization goals. Typically, hydrogen's viability will focus on "no-regret applications" that align with local conditions and individual ambitions about creating a hydrogen economy. Pakistan's local hydrogen use is predicted mainly for ammonia production in the fertilizer industry. There are a limited number of refineries that use hydrogen for desulphurization processes as well.

Exhibit - 1 present the anticipated timeline for hydrogen integration across sectors, identifying fertilizers as a primary candidate, as 22% of Pakistan's natural gas consumption supports hydrogen extraction within this industry. With high natural gas imports and declining domestic reserves, renewable hydrogen production through electrolysis offers an opportunity to enhance energy independence and food security while advancing the decarbonization of the agricultural sector.

Short-Term (2025-2035)	**Medium-term (2035-2050)**	**Long-term (2050-Onwards)**
Ammonia production in fertilizers	Long haul transport	Passenger cars
Desulphurizing agent in refineries	Industrial power generation-Combined Cycle Gas Turbines CCGTs	Storage option for flexibility
Methanol production	Reducing agent in steel industry	Shipping and aviation
		Fuel cells-based electrification

End use case	**Possibilities**	**Intervention**
Industrial feedstock	Yes	Direct applications i.e., green ammonia for fertilizers, refineries, and steel
Shipping and aviation	Yes	E-fuels (e-kerosene-ammonia and e-diesel) will be required for decarbonization
Hydrogen blending	No	The blending will increase the fuel cost without a significant reduction in emissions
Personal vehicles	No	Electric vehicles provide better efficiency than fuel cell vehicles
Public transport i.e., Trains and buses	No	Electrification of public transport is more cost effective
Electrification	No	Fuel cell-based power generation is not commercially viable
Buildings	No	Building level heating can be done by direct electrification
High temperature industrial applications	May be	If the technology achieves cost competitiveness it may present an opportunity

Exhibit - 1. Identified end used cases for hydrogen in short-, medium- and long-term scenario for Pakistan (RFs compilation)

Overall, navigating the hydrogen economy necessitates confronting the social and environmental challenges prevalent in EMDEs. A successful transition to an equitable and just hydrogen economy will be based on individual decarbonization targets and trade ambitions. A bilateral trade opportunity does exist between the Global North and Global South, which will be instrumental in cultivating a hydrogen market by capitalizing on the growth of this emerging sector. Exhibit - 2 presents the development parameters for green hydrogen developments based on renewable resource potential, localization of industrial components, and individual decarbonization ambitions.

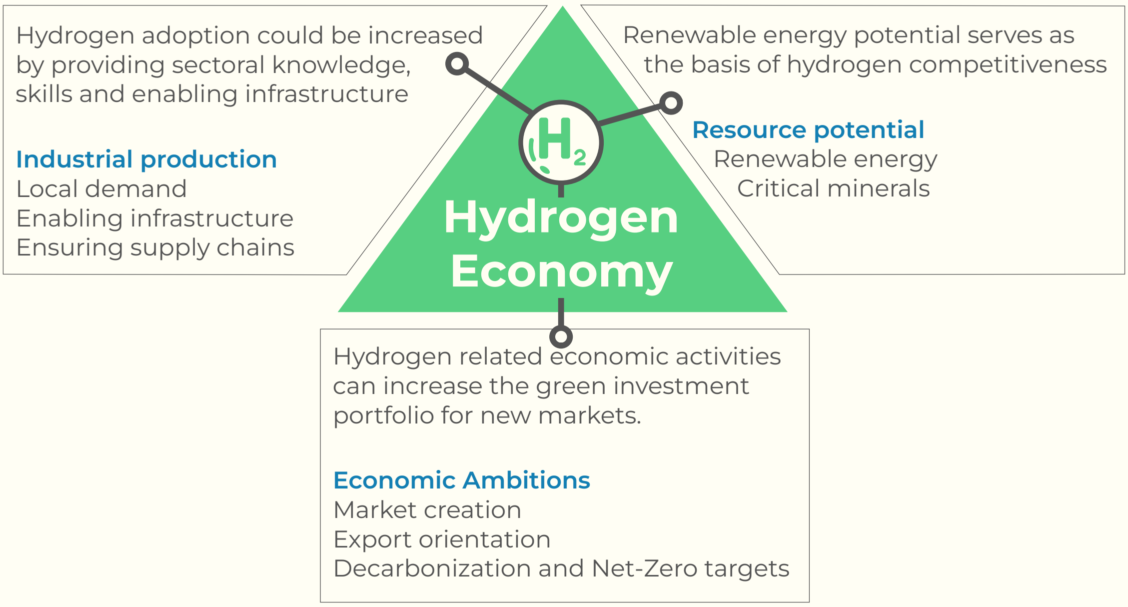


Exhibit - 2. Pyramid diagram of developing a hydrogen economy

Achieving a hydrogen economy and decarbonized industry is unattainable without a strategic approach to business opportunities and a supportive policy framework. Building a hydrogen economy focuses on generating demand and creating additional markets. Exhibit - 3 outlines the sequential steps necessary to commercialize green hydrogen within the context of climate neutrality goals.

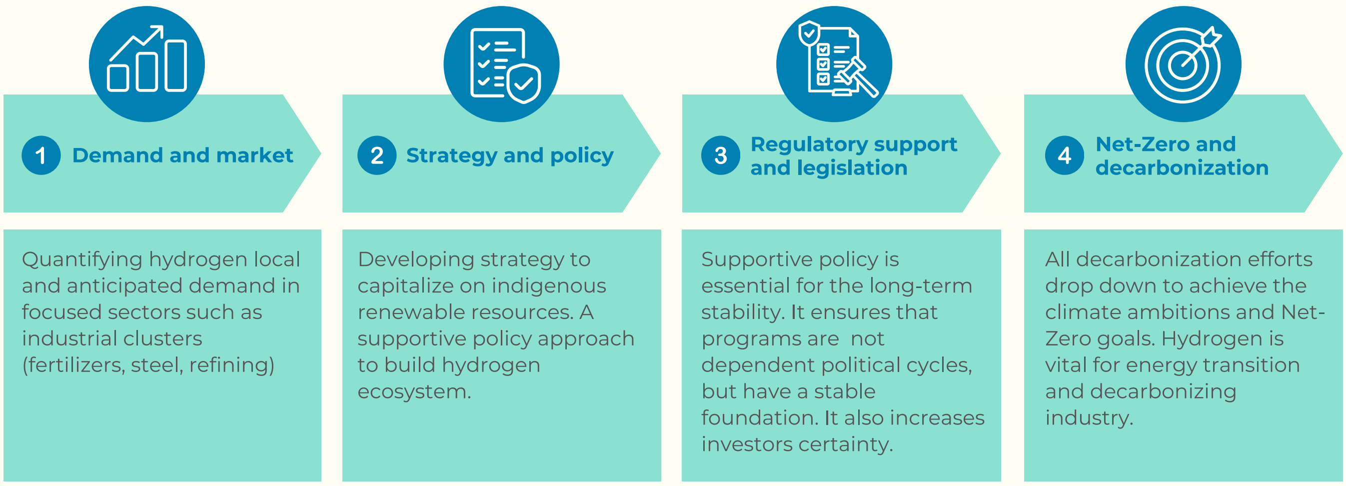


Exhibit - 3. Strategic approach towards developing a hydrogen ecosystem

Collaboration and international cooperation are essential for scaling up hydrogen infrastructure and ensuring its broad adoption. By utilizing hydrogen, countries can pave the way toward a sustainable, more resilient future, benefiting the environment and the economy.

The potential impacts of hydrogen development will require a dedicated focus on addressing the sustainability dimensions associated with them. Energy transition and decarbonization initiatives do require addressing multiple SDGs to realize a long-standing impact. For a successful transition to an equitable and just hydrogen economy that achieves a sustainable Net-Zero future, governments and industries need to intensify their efforts in creating actionable policies, and incorporating sustainability goals within the hydrogen development paradigm.

Figure - 2. Pakistan's intersecting SDGs with the green hydrogen economy

Green hydrogen and sustainable development goals

The 17 SDGs reflect the multidimensional nature of human development and economic security. A sustainable hydrogen economy holds the potential to bring about varied socioeconomic and environmental advantages, aligning with the SDGs. The scale-up of green hydrogen production potentially addresses multiple SDGs directly or indirectly (Figure - 3) [5]. The SDG Compass, a collaboration between the World Business Council for Sustainable Development (WBCSD) and the Hydrogen Council, is also being developed that aims to assist companies in incorporating SDG-driven principles into evolving hydrogen business models, following a roadmap set for 2024 [6].

Pakistan has integrated SDGs into national policies and developed an institutional framework for implementation, establishing support units at the federal and provincial levels. At present, SDGs that could include sustainable green hydrogen development are channeling USD 50M in funding towards addressing 5 out of the 17 SDGs, as illustrated in Figure - 2. Given the early-stage discussions on developing a green hydrogen strategy and policy, there is also an opportunity to prioritize SDG-5 on gender equality at an early stage of development, by requiring 50% representation of women across all sectors involved in developing the hydrogen market.

Sustainability dimensions: The EESG framework

The EESG framework is developed by the International PtX hub to promote sustainable practices in green hydrogen and PtX projects ensuring socioeconomic growth, and fair governance [7]. It is a strategic tool for addressing the sustainability of PtX projects presented in Exhibit - 4, providing a balanced approach by fully integrating the economic dimension into conventional ESG sustainability assessments. Each dimension addresses multiple sustainability issues, with their significance and impact depending on the relevance and risk profile of the specific assessment context, whether it involves a production process, an investment project, or a policy initiative.

Establishing hydrogen and PtX economies has significant social and societal impacts. The PtX value chain, from electricity generation to hydrogen production and its further conversion into various products through synthesis and refinement, involves numerous environmental concerns. While access to clean energy is a basic human right under sustainable development, it is also essential to consider the impact of these processes on biodiversity and life on land and water.

Exhibit - 4. The EESG framework (recreated from the EESG framework developed by International PtX Hub) [7].

Developing green hydrogen economy under EESG lens

Pakistan's current hydrogen demand is being met with natural gas. While some of it is sourced locally from indigenous gas reserves, the majority remains imported. Natural gas ranks as Pakistan's third-largest imported commodity, with imports valued at USD 3.95 billion (B) in 2022 [8]. The country's domestic gas reserves are limited and depleting rapidly, leading to increased dependence on imports. In 2023, domestic gas reserves decreased by 8.2%, while imports rose by 15%, exacerbating the ongoing energy crisis [9].

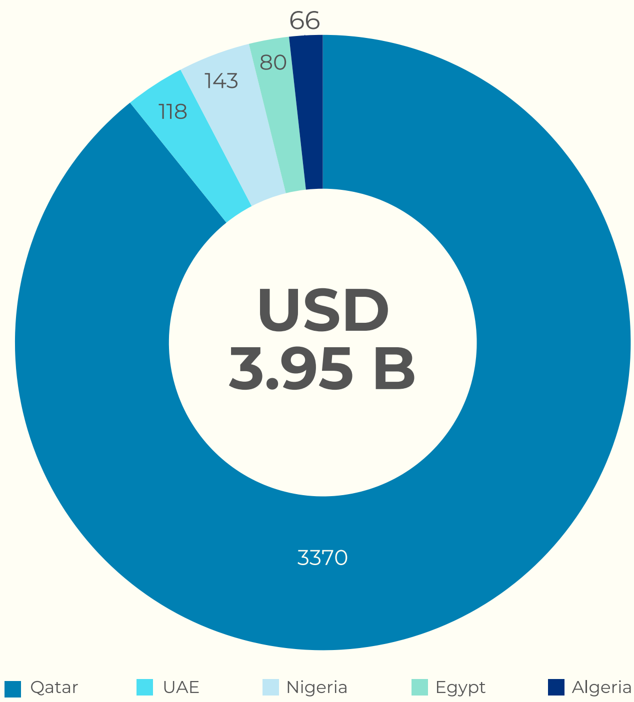


Figure - 3. Pakistan's natural gas import in 2022

Existing import dependencies in commodity markets are vulnerable to geopolitical tensions and market volatility, which undermines energy security. Figure - 3 highlights the LNG imports for 2022. Long-term continual use of natural gas as a feedstock for hydrogen production could increase natural gas imports, exacerbating issues like fuel shortages, declining reserves, and high import costs. This situation is further complicated by the industrial sector's fuel demand, current deficits and limited off-takers for expensive imported RLNG.

The high carbon emissions from grey hydrogen and focus on energy independence draw attention to the need for green hydrogen projects as a climate action and mitigation strategy. Table - 1 highlights the green hydrogen's parameters and indicators with the SDGs offering a suitable path to sustainable development.

Table - 1. EESG variables with indicators and contributors to SDGs (RFs compilation)

Environmental (E)

	Variable	Metric	Indicator	SDGs
1	Carbon footprint	Tons of CO2 eq/kgH2	Carbon emission per ton per kg of hydrogen production	13
2	RE integration	kWh/kg H2	Electricity required per kg of hydrogen production	7,13
3	Water usage and conservation	Water used per kg H2	Efficiency in utilization	6,14
4	Land use impact	Hectares	The area dedicated to electrolyzers and RE	3,11,15
5	Impact on biodiversity	Positive/negative	Implications for regional flora and fauna	14,15
6	Waste utilization	Tons	Percentage of waste recycled or safely disposed of.	12,13

Economic (E)

1	Cost Competitiveness	Cost per kg of hydrogen produced	Reduction in production costs over time.	9,17
2	Local demand and supply	Current local market scenarios	Market Pricing and offtake agreements	8, 10
3	Market creation and penetration	Market share in the energy sector	Increase in the adoption rate of green hydrogen.	8,9,17
4	Return on Investment (ROI)	Net present value (NPV) and internal rate of return (IRR)	Financial viability and profitability over the project lifecycle.	8,9
5	Infrastructure development	Invest in hydrogen infrastructure (Storage/transport)	Expansion of network and facilities	9,11
6	De-risking financial constraints	Innovative instruments	Finance mobilization for hydrogen projects	17
7	Employment opportunities and growth	Number of jobs created directly and indirectly	Employment growth rate	8, 11

Social (S)

1	Co benefits	Additional supply of electricity kWh and water (L)	Renewable electricity supply and water provisions	6,7,12
2	Community engagement	Number of community consultations and feedback sessions	Level of community support and involvement	8, 17
3	Social Equity and inclusion	Percentage of local and underrepresented groups employed	Equitable distribution of project benefits	5,8
4	Relevant education, skills, and on-the-job training	Number of training programs and participants	Skilling and reskilling local populations	5,8
5	Health and safety	Defined safety standards	Enhancement of local skills and knowledge base	3, 8
6	Cultural preservation	Impact on local cultural sites and practices	Measures taken to protect and respect cultural heritage.	11

Governance (G)

1	Clear and concise policy targets or strategy	Capacity targets (MW) (annual tons)	Achievable targets by a timeline	7, 9, 13
2	Legal and regulatory compliance	A clear framework	Adherence to local, national, and international regulations	16
3	Transparency and Reporting	Frequency and detail of sustainability reports	Stakeholder trust and accountability	16
4	Certification and standards	Transparent standardization	Adherence to international standards	9,16
5	Community and stakeholder engagement	Early involvement of communities	Stakeholder mapping and engagement plans	11,16
6	Ethical Practices	Compliance with sustainability	Integrity in business operations and decision-making	16
7	Risk Management	Number of identified and mitigated risks	Effectiveness of risk management strategies	11

1. E - Economy

1.1 Investment opportunities

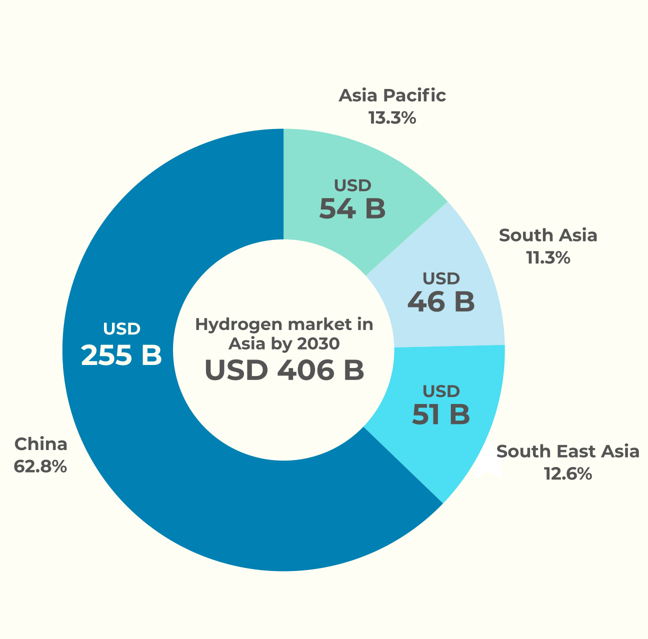
There is a growing need to assess the economic opportunity of hydrogen and implementing mechanisms like hydrogen auctions can facilitate market transition and realize the economic benefits. This shift could enhance energy security by reducing reliance on imported fuels, thus decoupling domestic energy consumption from global market fluctuations, and lowering national energy import bills.

Pakistan is a promising avenue for developing green hydrogen projects and can capitalize on its coastal regions' favorable wind and solar energy. Simulations by using Agora's PtX calculator predict achieving an optimum low LCOH by 2050 i.e., 1.00-2.00 $/kg [4]. The rapid decline of Chinese electrolyzers' prices could also help to achieve much lower LCOH. The potential for hydrogen usage within the Pakistani market appears substantial in the form of green ammonia for the fertilizer industry, indicating a promising future for green hydrogen in the country off-taking after 2030s.

Box - 2 Economic opportunity based on Hydrogen in Asian region

EMDEs, especially in Asia, can capitalize on hydrogen as a driver of economic growth. Most Asian nations are dependent on imported fossil fuels; hence hydrogen can reduce this demand and enhance energy security. By investing in hydrogen infrastructure and establishing supportive regulatory frameworks, these countries can attract investment, innovation, and gain competitive advantages in the emerging hydrogen market.

Green hydrogen market in Asia is predicted to reach USD 406 B by 2030 and approximately 24% of this investment will be mobilized in South Asian region as presented in Figure - 4 [2]. The grand economic turnover of hydrogen market is predicted, however unlocking the full potential requires regional cooperation through bilateral trade, offtake agreements, decarbonization goals, and multi-stakeholder engagement. Developing inter-regional markets in Asia can maximize hydrogen opportunities by investing in supportive infrastructure. Regions with high hydrogen production potential, capable of producing cost-effective hydrogen beyond local needs, can focus on export markets to facilitate the transition.



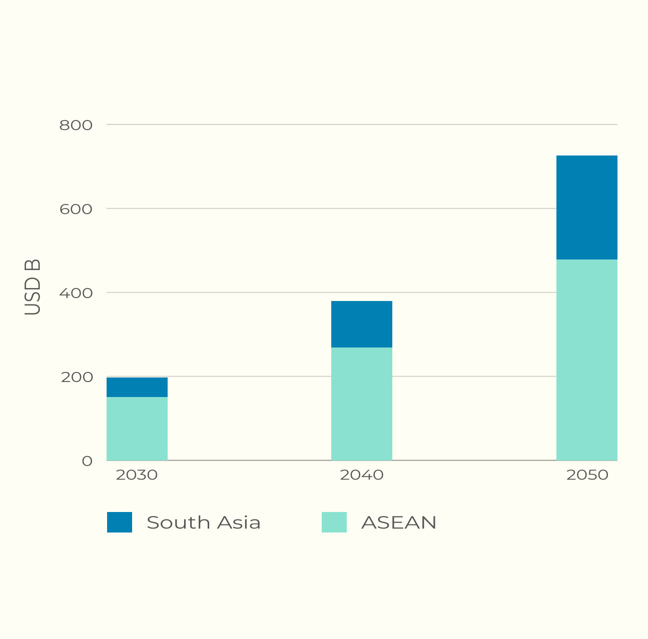


Figure - 4.Hydrogen market in Asia by 2030 [2].

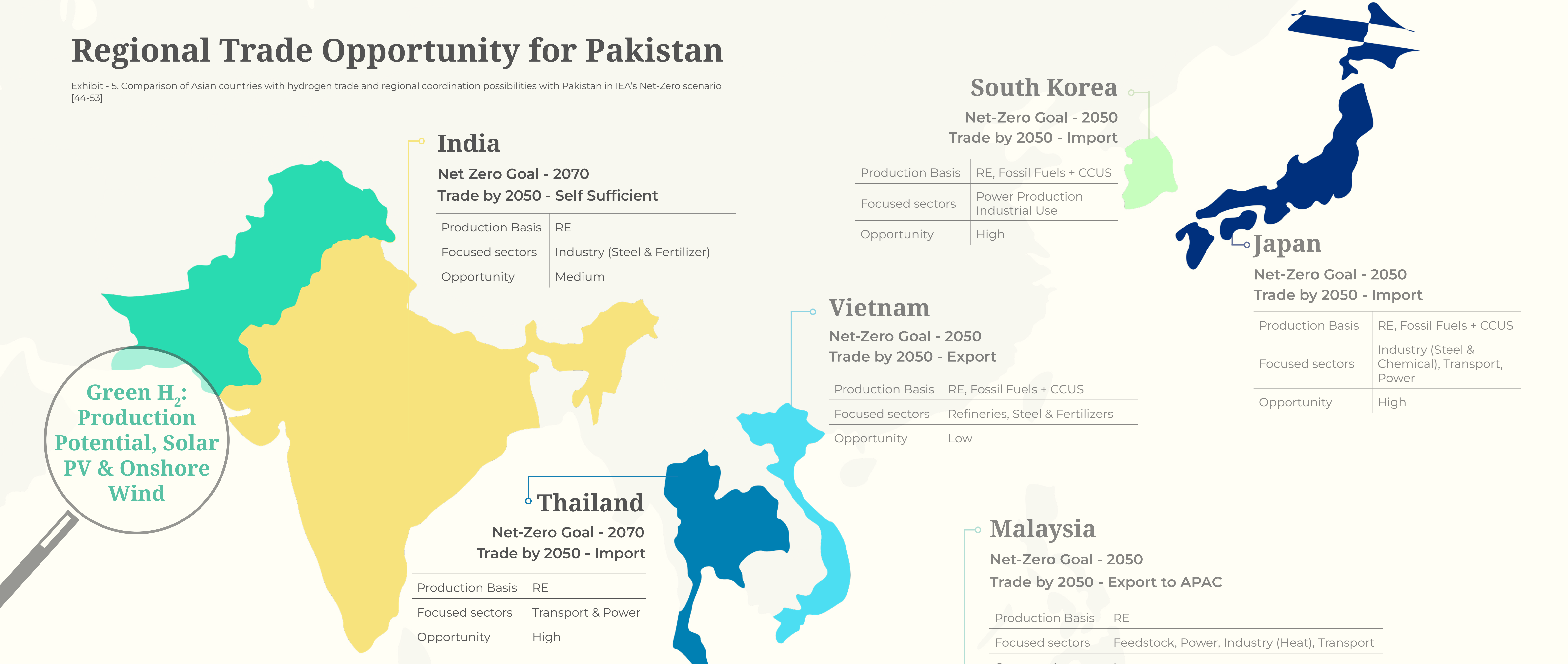
1.2 Bilateral trade and international cooperation

Pakistan's strategic location in Asia, coupled with its deep-sea port, positions it as a potential regional trade and cooperation hub. With Asia projected to account for 50% of global industrial hydrogen demand by 2050, [10]. Pakistan can leverage its indigenous resources and regional trade to meet this demand. This shift offers substantial opportunities for economic integration and collaboration with neighboring Asian countries.

Many central Asian countries are landlocked with no port infrastructure, complicating their trade logistics. Pakistan can help to enhance its connectivity to global markets by leveraging its deep seaport and economic cooperation. According to IEA's Net-Zero scenario, some Southeast Asian countries like Indonesia and Thailand are expected to depend heavily on imports of green hydrogen to achieve their industrial requirements. In the broader Asia-Pacific region, major economies like Japan and South Korea are also projected to significantly depend on hydrogen imports to meet their local energy needs [11]. Exhibit - 5. Represent the regional trade opportunity with Asian countries depending on their hydrogen demand compiled from various sources.

Regional Trade Opportunity for Pakistan

Exhibit - 5. Comparison of Asian countries with hydrogen trade and regional coordination possibilities with Pakistan in IEA's Net-Zero scenario [44-53]



India

Net Zero Goal - 2070
Trade by 2050 - Self Sufficient

Production Basis	RE
Focused sectors	Industry (Steel & Fertilizer)
Opportunity	Medium

South Korea

Net-Zero Goal - 2050
Trade by 2050 - Import

Production Basis	RE, Fossil Fuels + CCUS
Focused sectors	Power Production Industrial Use
Opportunity	High

Japan

Net-Zero Goal - 2050
Trade by 2050 - Import

Production Basis	RE, Fossil Fuels + CCUS
Focused sectors	Industry (Steel & Chemical), Transport, Power
Opportunity	High

Vietnam

Net-Zero Goal - 2050
Trade by 2050 - Export

Production Basis	RE, Fossil Fuels + CCUS
Focused sectors	Refineries, Steel & Fertilizers
Opportunity	Low

Thailand

Net-Zero Goal - 2070
Trade by 2050 - Import

Production Basis	RE
Focused sectors	Transport & Power
Opportunity	High

Malaysia

Net-Zero Goal - 2050
Trade by 2050 - Export to APAC

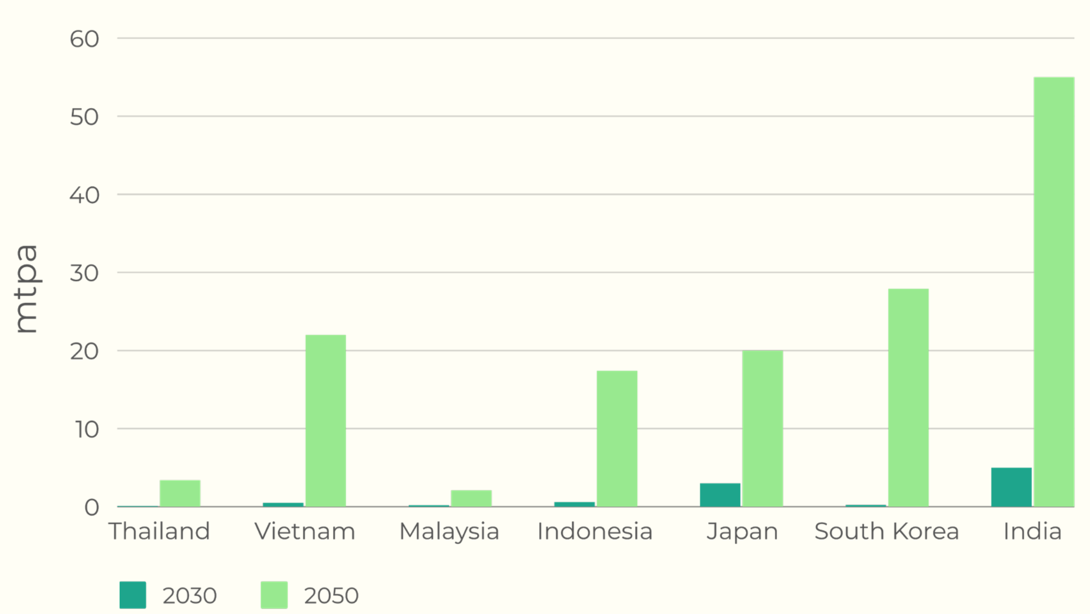
Production Basis	RE
Focused sectors	Feedstock, Power, Industry (Heat), Transport
Opportunity	Low

Indonesia

Net-Zero Goal - 2060
Trade by 2050 - Import

Production Basis	RE
Focused sectors	Industry (Steel & Commercial)
Opportunity	Medium

Country-wise H_2 Demand



For interregional hydrogen transportation, pipelines could offer a competitive advantage, enabling transport of up to 3,000 km by retrofitting existing natural gas infrastructure. This range could be extended to 7,000 km with further modifications [2]. For distances over 7,000 km, shipping hydrogen derivatives like ammonia becomes a viable option. These derivatives also hold additional market potential for use in various industries. Under regional trade alliances, projects such as the Turkmenistan–Afghanistan–Pakistan–India (TAPI) gas pipeline are already in place for natural gas trade.

While there is potential to extend the hydrogen exports to European markets, the high shipping costs involved may not present a competitive advantage for Pakistan. The distance-associated transportation expenses could undermine the economic feasibility of exporting hydrogen in that case. Nonetheless, the Asian region offers a more viable and strategic pathway for Pakistan to enhance its economic prospects and regional influence on energy transition.

1.3 Economic implications and risks

The economic dimension of energy transition and hydrogen energy is more critical as it does offer opportunities, but it comes with potential risks to trade and alliances. Though green hydrogen trade will not be in the form of conventional fossil-based economy market, ensuring the persistent supply of RE, electrolyzer equipment and compliance with decarbonization targets.

The primary economic risk centers on the absence of an established market and secure off-take agreements. The high cost of renewables-based hydrogen leads to reluctance among potential buyers to commit to its purchase. Without assured buyers, developers face difficulty securing financing and moving projects forward, while investors are hesitant to fund ventures without clear indications of market viability and profitability.

Many developing states including Pakistan struggle with socio-economic challenges due to political instability that could eventually impact the hydrogen industry in future scenarios. Though having good hydrogen production potential, they may suffer to fully capitalize on it. Considering, Pakistan's rankings — 128 in the Global Governance and 139 in the Environmental Performance Index — highlights the need for significant policy reforms. These include improving regulatory frameworks, enhancing environmental standards, and addressing governance challenges to attract international investment [12].

Importantly the existing cost disparity between green and grey hydrogen indicates that government support is necessary to stimulate market growth. Given the crucial role of renewables-based hydrogen in the energy transition, it is essential to pursue international cooperation at an early stage. By establishing international agreements, setting standardized regulations, and coordinating industrial policies, governments can create synergies in climate and energy policies, creating a thriving market that benefits all stakeholders involved.

1.4 De-risking green hydrogen projects

De-risking hydrogen finance remains a crucial point, and it requires a strategic approach to ensure certainty of investments. As of the 2023 review, only 4% of the projects in the pipeline have reached a final investment decision [13]. Capital mobilization can be supported by concessional funding from public sources and blended finance. De-risking instruments to derive the hydrogen derivative business model require off-taker-centric developments. Moreover, forging public-private partnerships can be instrumental in leveraging larger financial resources and expertise from both sectors.

Establishing long-term offtake agreements is necessary to generate stable revenue streams to reduce market risks [14]. Aligning interests between equity holders and off-takers nurtures collaboration and shared goals, enhancing project viability. Exhibit - 6 represents the key enablers of de-risking finance for market creation and market growth to achieve a Net-zero hydrogen economy. Credible stakeholders can play a key role in mitigating technology and construction risks, ensuring projects are completed successfully. Strategic alliances such as public-private partnerships supporting the decarbonization initiatives could help expand market viability.

In EMDEs government-backed insurance and guarantees can play a crucial role in mitigating currency risks in these regions. This support makes it more attractive for investors to engage in projects, as it minimizes the potential financial losses that can arise from currency volatility.

Exhibit - 6. Enablers for de-risking hydrogen projects for market creation and growth

Box 3 - Global developments for de-risking hydrogen project developments

United Kingdom

Hydrogen Allocation Rounds (HAR)

The Hydrogen Allocation Rounds distribute revenue support to hydrogen production facilities across the UK through the Hydrogen Production Business Model (HPBM). In July 2022 HAR - 1 selected 11 successful projects for contract offers of 125 MW capacity. It is anticipated that projects will become operational by 2025. The UK has ambitious hydrogen targets focusing on adding 1 GW by 2025 of electrolytic hydrogen to contribute towards the overall 10 GW target of low carbon hydrogen.

HAR - 1 places the UK at the forefront internationally, marking the largest simultaneous announcement of commercial-scale green hydrogen production projects in Europe. This round offered GBP 2.00 B in revenue support through HPBM, which will commence once the projects are operational. A Net-Zero Hydrogen Fund of GBP 90 million (M) has also been allocated to aid in the construction of these projects. HAR-2 is currently underway, with the goal of supporting 850 MW of electrolysis-based projects [15].

European Union (EU)

European Hydrogen Bank Auctions

European Hydrogen Bank was established in 2022 with the main aim to unlock private investments both in European Union (EU) and international market by overcoming supply-demand and initial investment challenges. The bank granted almost euro 720 M to seven renewable hydrogen projects in Europe, chosen through the inaugural competitive bidding process. Bids submitted ranged from euro 0.37 to euro 0.48 per kilogram of renewable hydrogen produced, with the subsidies awarded varying from euro 8 M to euro 245 M [16].

1.5 Potential of hydrogen projects in the carbon markets landscape

Empowering carbon markets will be pivotal to channel finance in developing green hydrogen projects. According to Bloomberg NEF, these markets could reach a value of USD 1.1 T as part of the Net-Zero transition [17]. Initiatives such as "Hydrogen for Net-Zero (H2NZ)" are establishing methodologies to mobilize carbon finance in the Voluntary Carbon Market (VCM) that would bridge the finance gap [18]. Cost competitiveness will only be achieved if capital intensity is addressed, and international financing is secured by mitigating potential financial risks. Currently, hydrogen standardization and certifications are still in the development phase, a uniform international standard for benchmarking projects will be necessary in the future.

This also presents a huge opportunity for Pakistan as its already working on developing its VCM framework. Historically, it has successfully tapped the carbon market with the landmark "Delta Blue Carbon Project" to produce high-quality Blue Carbon Credits (BCC) through interventions over the project's 60-year lifespan. The project safeguards 102,000 hectares of existing mangrove forests and is rehabilitating and restoring an additional 226,000 hectares of degraded and deforested mangrove areas [19].

The carbon markets policy is under development, yet Delta Blue Carbon was still able to generate USD 200-250 M in revenue by mitigating 250,000 tons of CO2 through carbon offset credits [20].

Considering a significant reduction in carbon emissions associated with existing hydrogen processes, the development of green hydrogen projects can be pledged for carbon credits to be traded in the international market. It will help bridge the financing gap and de-risk investments in case of high socio-political uncertainty. For instance, the European Hydrogen Bank was established by revenues generated by its Emission Trading Scheme (ETS), for further details see Box - 3.

Box - 4 India's initiative to stimulate carbon credits market for renewable energy and hydrogen projects

In India, the World Bank approved the USD 1.5 B First Low-Carbon Energy Programmatic Development Policy Operation. It set forth a strategy to issue 50 GW of renewable energy tenders annually and created a legal framework for a national carbon credit market. The plan also indicates ramping up the hydrogen market by adding 1.5 GW of electrolyzers annually by 2025-26. It also gives incentives to waive of transmission charges for renewable energy in green hydrogen projects. The operation is aiding in increasing investments in green hydrogen and renewable energy infrastructure by attracting the private sector investments through competitive bidding [54].

2. E - Environment

2.1 Emission paradigm and Net-Zero pathway

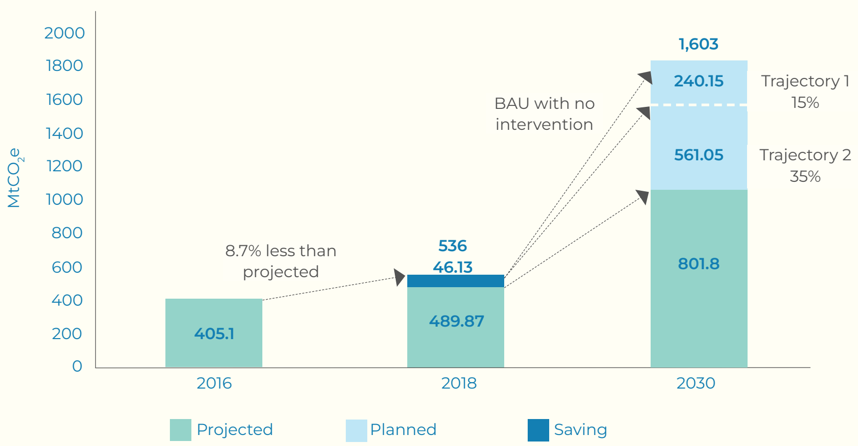


Figure - 5. Projected overall emissions in Pakistan updated NDCs [21]

Pakistan being the signatory of the Paris Agreement (2015) pledged Nationally Determined Contribution (NDCs) at 15% conditional value and 35% unconditionally depending on international support by 2030. Figure - 6 illustrates the emissions reduction under various scenarios [21].

In Pakistan, the primary sectoral emissions come from cement plants, transportation, fertilizer, agriculture, gas processing, power plants, and refineries [22]. Following its first GHG inventory, Pakistan achieved an 8.6% reduction in emissions by 2018 compared to projected levels highlighted in Figure - 5.

The country is announcing its Net-Zero targets and developing its strategy. Industrial decarbonization and deffosilization render hydrogen at the heart of the transition. Therefore, hydrogen strategy must be strongly aligned with the national ambitions of achieving Net-Zero targets. The fertilizer production and refinery sectors could play a critical role in reducing carbon emissions industries. Green fertilizers could also help to reduce agriculture-related carbon emissions.

Developing green hydrogen projects can contribute to Pakistan's NDCs in both conditional and unconditional categories with more emphasis on producing green ammonia. Thus, supporting the green hydrogen economy can effectively reduce national emissions and generate revenue through carbon credit and bilateral trade opportunities.

2.2 Water uptake for electrolysis

There has been extensive discussion and concerns about water utilization for hydrogen production. It has been anticipated that only 2% of the total consumption of water will be required for green electrolysis by 2050 [23]. Figure - 6 projects the sectoral water consumption by 2050, with agriculture being the most significant user. Water consumption for green electrolysis is expected to increase from 0.6 bcm in 2023 to 24.8 bcm by 2050. This dispels the major myth that green molecules require enormous and unattainable amounts of water [23].

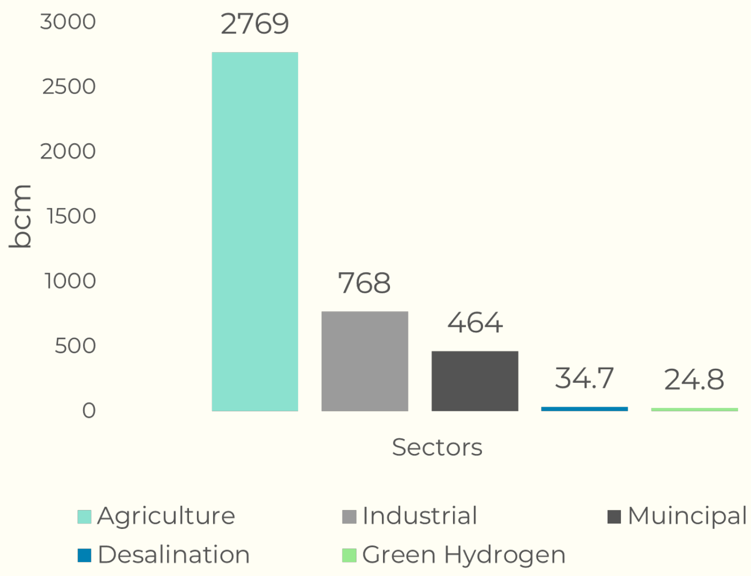


Figure - 6. Water consumption at sectoral level by 2050 (IRENA)

All other techniques for hydrogen production also require huge water consumption for downstream cooling processes. Water requirements for green electrolysis water are like the production of grey hydrogen through Steam Methane Reforming (SMR) process. Figure - 7 provides a comprehensive overview of water utilization required by each technology. Proton Exchange Membrane PEM and Alkaline electrolyzers both consume the least amount of water. Hydrogen production through Coal gasification utilizes the highest amount of water coupled with Carbon Capture Utilization and Storage (CCS/CCUS).

In the case of electrolysis, water utilization is also reduced by increasing electrolyzer efficiency. A 1% improvement in electrolysis efficiency results in a 2% reduction in both water withdrawal and consumption needs for green hydrogen production [23].

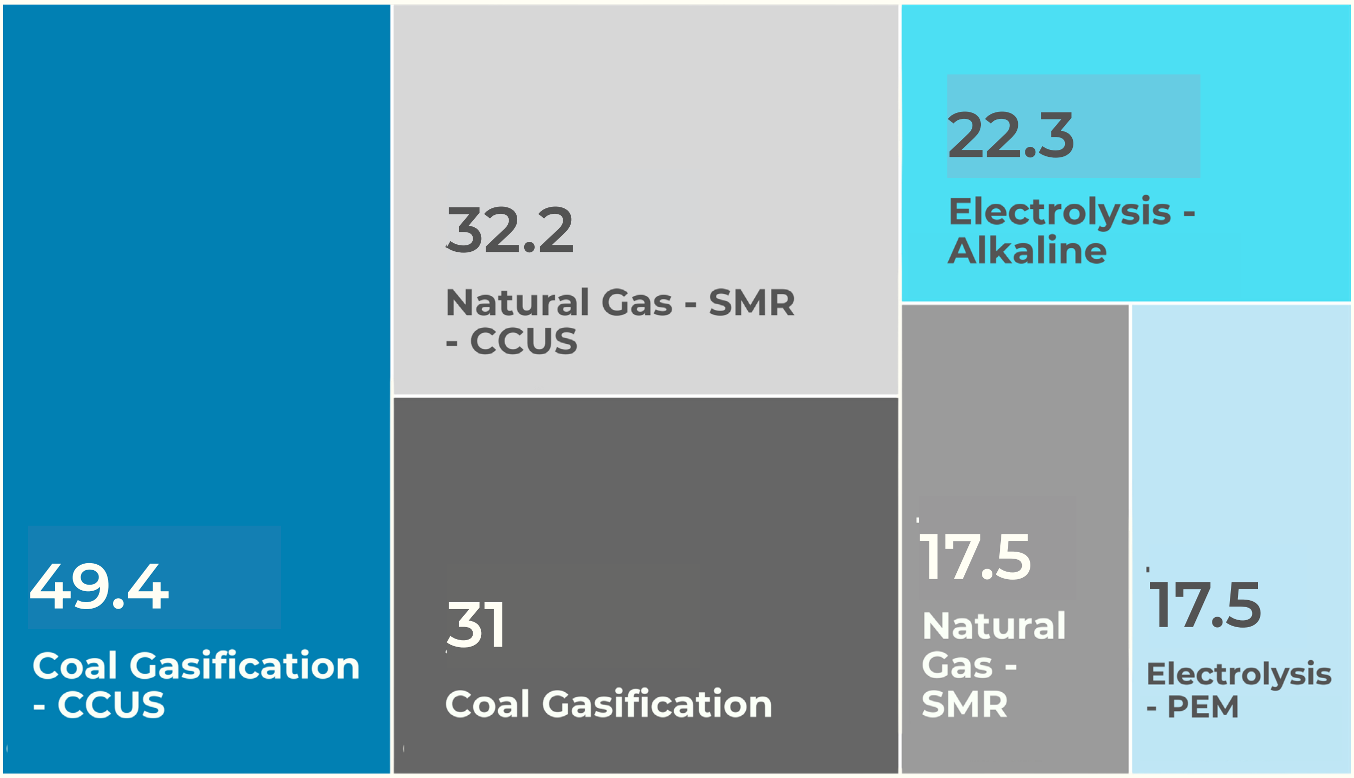


Figure - 7. Water consumption by different hydrogen production technologies [24]

In Pakistan, Sindh and Balochistan offer significant potential for green hydrogen production due to their RE resources and proximity to water sources. Sindh's Gharo-Jhimpir wind corridor is ideal for powering electrolyzers, while freshwater lakes like Keenjhar and Haleji could support water needs [25]. For agricultural purposes, 77% of the land in Sindh is irrigated and usually faces water scarcity in summer months [26].

The water risk atlas presented in Figure - 8 indicates that Pakistan is under medium to high water scarcity risk. To mitigate water scarcity from natural sources, hydrogen production must be carefully regulated through environmental assessments. Priority should be given to implementing technologies like desalination and water recycling to ensure a sustainable balance between energy production, agricultural demands, and ecological preservation. Any green hydrogen development in the region must be designed not just to avoid adding to these water pressures, but to help solve existing water management problems through improved infrastructure and technology.

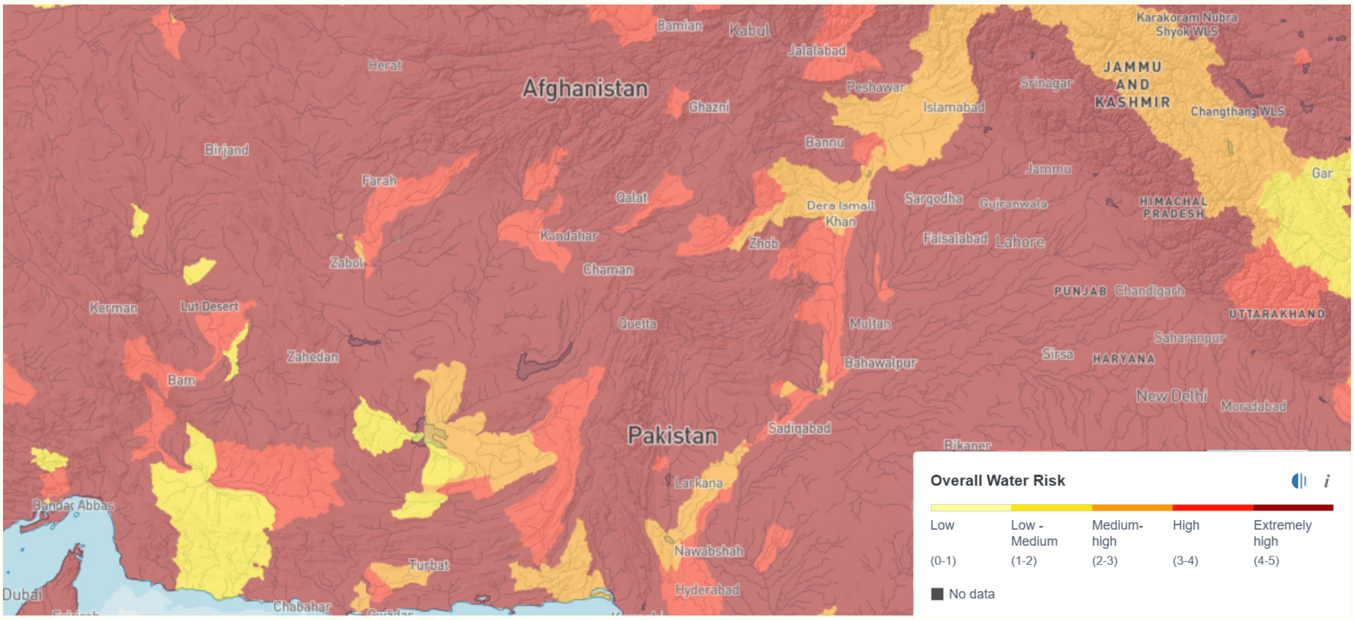


Figure - 8. Aqueduct-Water Risk Atlas (2024) by World Resource Institute shows Pakistan's water risk

Green hydrogen developments present an opportunity for co-benefits by addressing exacerbated water stress challenges through seawater desalination. Water supply systems tailored for hydrogen production could be expanded to also fulfill other water needs for clean drinking water supply, especially in areas of water scarcity, the use could also be expanded for sanitation and irrigation purposes, at minimal extra costs for hydrogen production presented in Figure - 9. Often, the concern of added cost and brine management of seawater desalination is raised, however it is a small component of USD 0.01-0.02 per kg of total LCOH of green hydrogen [27]. Seawater desalination is only 2% of the total green hydrogen production including the treatment and transport cost [28].

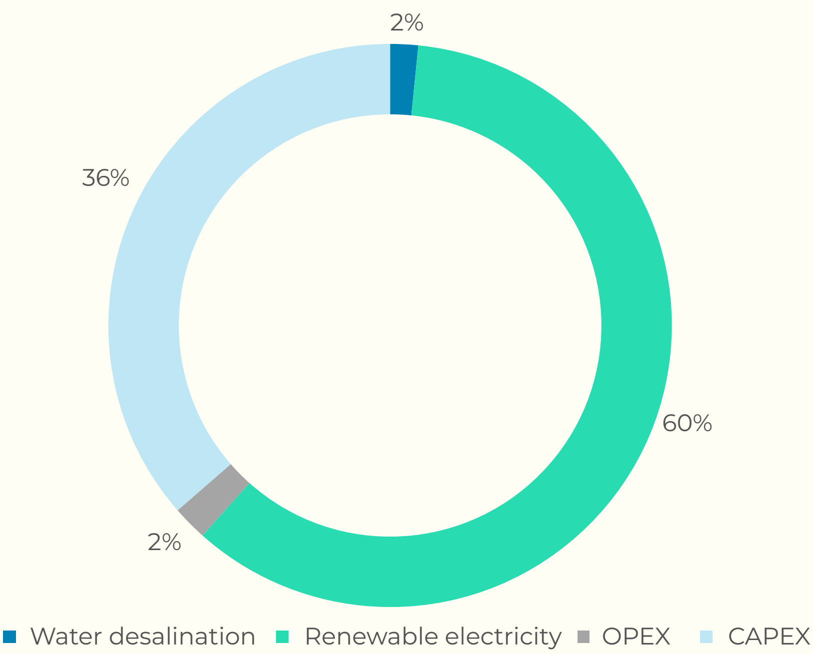


Figure - 9. Cost Breakdown of a Green Hydrogen Project [24]

Box - 5 Brine disposal

Brine is a byproduct of seawater desalination, and its disposal poses an environmental concern. Mostly, this high salinity untreated water without proper disposal at coastal sites can cause a threat to marine ecosystems. Managing brine is a crucial factor in reducing the environmental impact and addressing the environmental concerns related to desalination.

In an additional use, water mining of brine can potentially create an additional income stream by extracting minerals, salts or metals. However, the economic viability of water mining is not guaranteed and should be assessed individually for each desalination project.

Currently, there are no regulations or standards for brine disposal. With the expected increase in desalination, policymakers should establish regulations. They need to evaluate local conditions, such as chemical composition and quantity, salinity, and the overall volume of brine, to address sustainability.

2.3 Land use requirements

Each project may have unique land needs depending on whether the electrolysis requires dedicated renewable power, or it will be added to an existing renewable grid. Dedicated RE supply such as wind and solar photovoltaic (PV), will require significant land. For example, a 100 MW solar PV power plant requires 2 square km of land, while an onshore wind power plant needs 4.8 square km, whereas an electrolyzer has the smallest land footprint among them as illustrated in Figure - 10 [29]. RE has a smaller land footprint compared to other electricity generation sources so ensuring land availability is still essential.

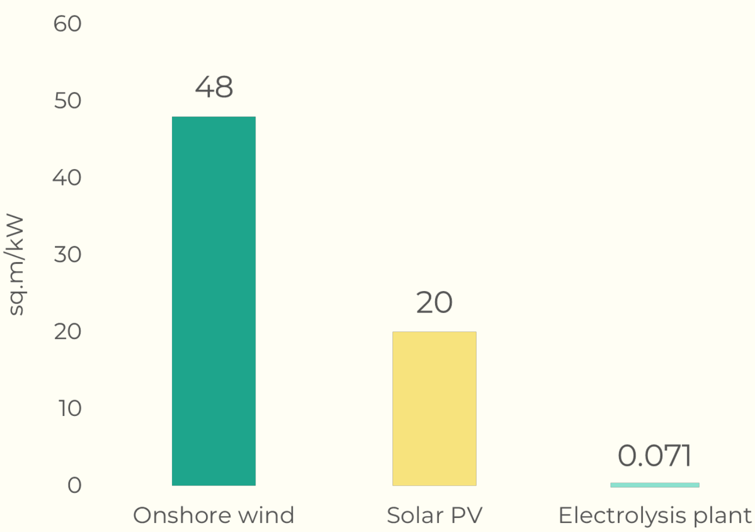


Figure - 10. Land use requirements for different technologies

The most favorable green hydrogen production opportunities are typically in coastal areas with steady wind patterns, access to water for electrolysis, and dedicated shipping provisions. However, these coastal regions tend to be more densely populated than inland water resources, making land acquisition challenging due to non-availability and ownership issues. According to EY, one of the major barriers faced by developing countries including Pakistan are significant delays in land acquisition and a lack of regulations regarding ownership [30].

As a nascent industry green hydrogen lacks the regulatory framework that addresses the land use regulations and legislation. To ensure the successful implementation of hydrogen and PtX projects, pre-feasibility studies must carefully address land acquisition, anticipated costs, and lease agreements. From a legal perspective, this is crucial to avoid unexpected delays in acquisition. A clear legal framework for land use rights can facilitate the evaluation, implementation, and financing of large-scale green hydrogen projects.

2.4 Life cycle assessment of green hydrogen projects

Life Cycle Assessments (LCAs) provide a standardized method for evaluating environmental impacts across a product's entire life cycle. For LCA's of hydrogen projects, IPHE methodology is anticipated to be a standardized procedure developed by IPHE (International Partnership for Hydrogen and Fuel Cells in the Economy). IPHE is a collaborative initiative aimed to accelerate fuel cell and hydrogen technologies at government level to enhance energy and economic growth. In recent communication (2023) IPHE introduced the “Well to Grate” system boundary, ensuring that all GHG emissions related to the hydrogen production process are accounted for. Figure - 11 highlights the ‘Well-to-grate” boundary mechanism that addresses the emission spectrum [31].

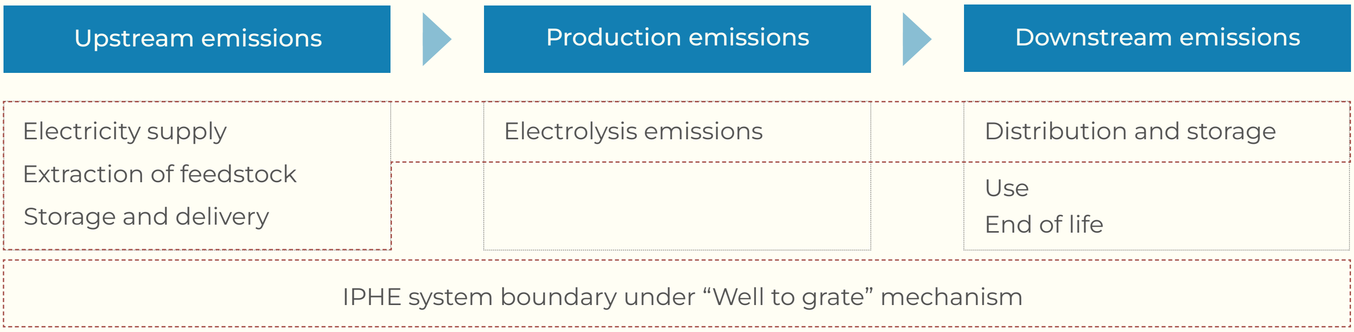
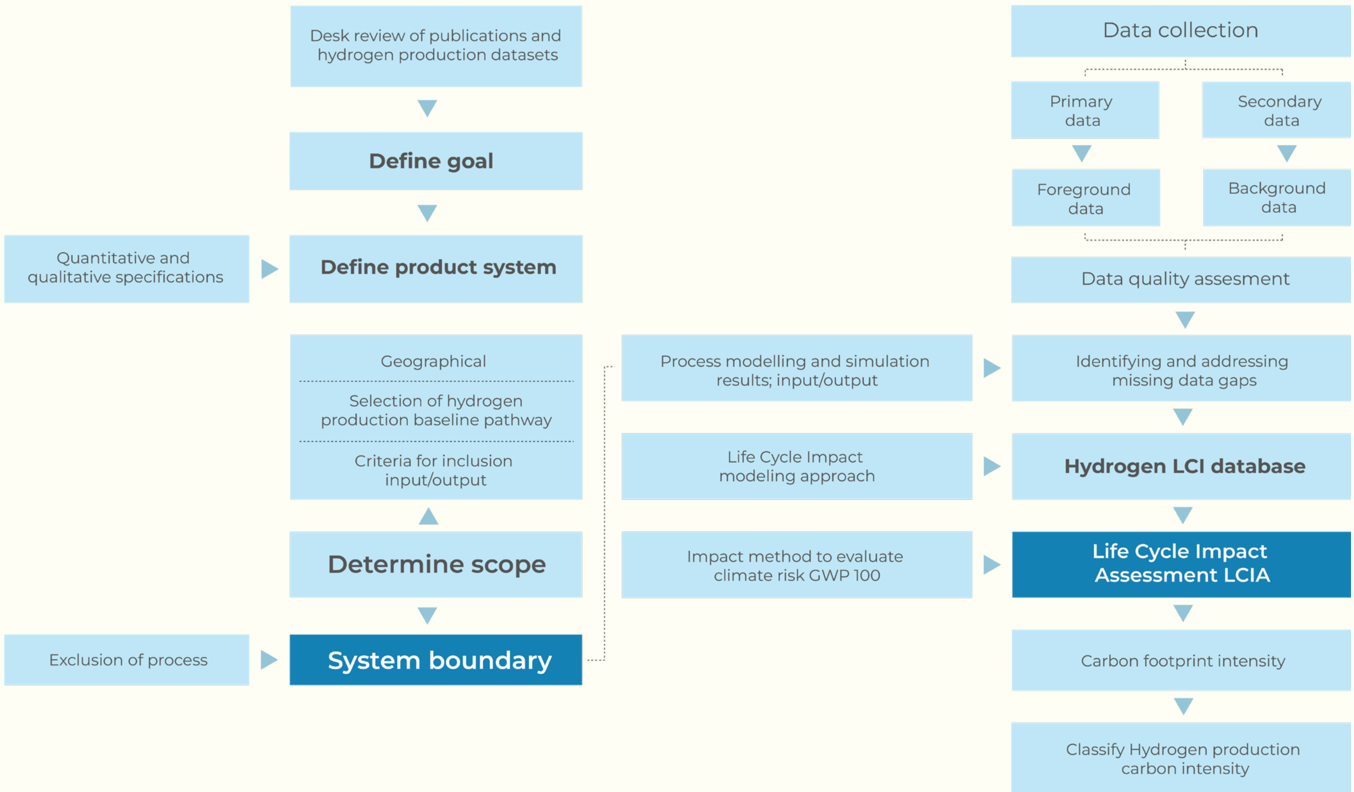


Figure - 11. System boundaries in IPHE methodology for hydrogen production

GHG emissions from electricity pertain to the plant's electricity consumption, accounting for upstream, operational, and downstream emissions. Electricity sourcing is also categorized into two main areas, i.e., onsite dedicated renewable electricity, and grid-based electricity. The emissions associated with the electricity sourced from the grid will require quantification of all the sources it is generated from.

The IPHE methodology is already applied in voluntary programs and standards, such as the Green Hydrogen Standards by the Green Hydrogen Organization (GH2). Once adopted as an ISO standard, this methodology will become widely used as a reference framework for certification mechanisms and standards globally.

A uniform LCA methodology is essential to ensure sustainability and data quality to be referred to as an ISO standard. Exhibit - 7 outlines hydrogen production within the LCA framework, following the four ISO phases. Table - 1 summarizes commonly agreed criteria for hydrogen production LCA. During assessments, defining the system boundaries is one of the key parameters that would require what criteria could be included or excluded. However, data availability can be a challenge, especially for new and emerging technologies [32].



Exihibit-7. Process flow and framework of hydrogen production LCA

Table - 2. Agreed Life cycle assessment criteria for hydrogen production mainly [32]

Life Cycle Assessment Stage	Criteria	Level of Agreement
Hydrogen Product System Information	Purity >= 99.9%	High
	Pressure > 3 Mpa	Low
Goal and Scope Definition	Unambiguously define the goal of the study	High
	Cradle-to-gate system boundary	High
	Compression process included in the system boundary Low	Low
	Use energy (MJ H2) of produced hydrogen as the functional unit	Low
	Use mass (kg H2) of produced hydrogen as the functional unit High	High
	Use the ISO physical allocation for solving multifunctional processes	High
	Processes rated to embedded emissions from construction, manufacturing of capital goods excluding from system boundary	High
Life Cycle Inventory Analysis	Define data quality requirements according to ISO standards	Very low
	Use primary data for the foreground processes	Low
	Fill data gaps with secondary data	High
Life Cycle Impact Assessment	Global Warming Potential impact method	High
	IPCC as an impact method	Low

3. S - Social implications in green hydrogen developments

3.1 Empowering vulnerable communities

For a just transition, green hydrogen projects should positively impact local communities by empowering them and ensuring their involvement. Failure to engage effectively can lead to conflicts, resulting in financial and operational risks such as delays, litigation, and even cancellations. A re-design of projects towards benefits for local communities can lead to additional local co-benefits [29].

While Pakistan's hydrogen sector is in its early phases, the proposed remote sites are surrounded by rural populations. To maximize social benefits, project development must prioritize local community needs while safeguarding against potential negative impacts. Table - 3 Describes the factors influencing developments and their effects on the local community. Addressing mitigation activities can help ensure an equitable distribution of benefits, including opportunities for women and other vulnerable and marginalized groups.

Table - 3. Potential impact issues and mitigation activities on the local communities

Sr.no	Potential impact	Cause	Impact		Mitigation activities
1	Land allocation and enclosure issue	Land requirement for RE and electrolyzer	Direct	Negative	Avoid agricultural land to minimize the project footprint Early engagement with landowners
2	Diversion and utilization of scarce water resources	Water scarcity Misconception about water usage for hydrogen	Indirect	Negative	Awareness and demonstration of water management
3	Diversion of electricity and grid bottlenecks	Load shedding Misconception about high electricity consumption	Indirect	Negative	Awareness and education about RE
4	Access to long-term economic opportunities	Misconception about short-term opportunities	Indirect	Positive	Awareness about the local skills and resources need
5	Employment opportunities	Lack of localized skilled force	Indirect	Positive	Creating skilled jobs for the local population Training and development opportunities
6	Co-benefit of excess water and energy	Lack of energy access due to remoteness of potential site Water scarcity	Direct	Positive	Ensuring continued access to clean energy and water should be a permanent goal, or at the very least sustained during the project's execution
7	Financial incentivization of local government and population	Low development of rural areas Lack of infrastructure	Direct	Positive	Enabling the local community to become investors, like citizen energy initiatives in Germany or Chile, is an effective way to enhance benefits for the community and increase project acceptance
8	Relocation expenses for skilled labor	Rising living costs for community members, such as those caused by an influx of well-paid experts	Indirect	Negative	This issue could be mitigated by training the local workforce and equipping them with the necessary skills to handle new opportunities and challenges that arise from the project
9	Realizing local co-benefits	Attraction for local communities is important for social acceptance	Indirect	Positive	In a water-scarce country, a green hydrogen project could be paired with an agricultural venture that relies on the additional water from the project's desalination plant

3.2 Social justice and inclusion

Just Energy Transition requires embedding social justice as one of the crucial elements of sustainable development. According to the SDGs, access to clean energy, infrastructure, innovation, and strategic partnerships are fundamental human rights [5]. However, social justice is a missed shot in most technological development scenarios. For instance, early-stage development of RE projects was affected by opposition from local communities.

Gaining local public acceptance is essential for the placement and development of energy infrastructure. The opposition can delay the approval and permitting process, and in some cases, it can completely halt projects. Further adding to it is NIMBYism, detailed in Box - 6, is the term coined in the United States (US) which represents a significant social attitude among the public who oppose development in their immediate vicinity.

Pakistan also has an example of socio-political challenges impacting energy projects, such as the Kalabagh Dam. The project remains stalled despite receiving feasibility approval from experts over three decades ago. Feasibility studies have emphasized the necessity of a dam to address the severe water crisis and ensure consistent irrigation flow. A 2014 research study highlighted that the Kalabagh Dam, with its 3,600MW electricity generation capacity, could save the country USD 4 B annually on fuel import bills. Additionally, around 30 M acre-ft of water is wasted into the sea due to the lack of large water reservoirs [33].

Box - 6. NIMBYism

NIMBY is an acronym for "Not in My Back Yard," it refers to a collective stance of a community towards certain development changes in occupancy of an existing neighborhood as inappropriate or unwanted for their local area [34]. This kind of resistance poses serious delays in initiating projects and could also lead to unnecessary financial drainage. In most cases, renewable energy projects have also been impacted by this movement. For instance, it impacted US's initiative to develop the largest solar power plant, the "Battle Born Project," with a capacity of 850 MW, was canceled due to opposition from the local community in Nevada's Moapa Valley. Although the project was projected to supply clean energy to 500,000 homes during sunshine hours and create 2,600 local jobs, residents contended that it constituted an inappropriate use of public land [35].

3.3 Employment opportunities

Hydrogen strategies are mostly developed with long-term employment and economic opportunities at national level. Many countries are focused on creating local jobs and supporting local businesses that can help to gain public approval for hydrogen and PtX projects that involve infrastructure development, such as roads or transmission grids. However, it is crucial to maintain that the forecasted benefits genuinely enhance the living conditions of the neighboring communities.

There are significant employment opportunities at each step of developing hydrogen value chain. In a specific planning example, India expects its National Hydrogen mission to create 600,000 jobs by 2030 to meet its hydrogen production target of 5 million tons per year [36].

The opportunities in the hydrogen market can be divided into temporary (immediate) and permanent (long-term) categories. Temporary roles include construction workers, project engineers and managers, Front End Engineering Design (FEED) experts, and planning engineers. Permanent, long-term roles employ operations personnel and managers, facilities engineers, and Operations and Maintenance (O&M) workforce. Transparent assessments must be undertaken to identify national or regional job potential.

Establishing a local RE supply chain could also help to potentially generate more long-term economic stability opportunities. For instance, manufacturing PV solar modules, wind turbines, electrical connections, or cables in EMDEs will create additional local jobs providing more stability over short-term gains.

Hydrogen project development in Pakistan offers significant potential for local employment creation. Currently, local expertise in Pakistan is predominantly focused on Solar PV and Wind energy project development, highlighting the need for targeted capacity-building initiatives in emerging hydrogen technologies. Offering appropriate training could empower them and integrate the local workforce into creating the hydrogen ecosystem. Re-skilling, the existing workforce would certainly demand additional expertise and financial support.

3.4 Co-benefits of developing hydrogen infrastructure for local communities

Many of the hydrogen's potential sites are in remote areas without electricity or have limited access to it. By incorporating excess RE capacity during the planning stages, hydrogen projects can bring much-needed electrification to local communities. Such development can enhance regional energy needs while stimulating economic growth and raising living standards for residents.

At its core, the project aligns with five key SDGs as illustrated in Figure - 12. These interconnected goals can address the sustainable development of the region, i.e., SDG-6 (clean water and sanitation), SDG-7 (affordable clean energy), SDG-8 (economic opportunities), SDG-10 (reduced inequalities), and SDG-12 (responsible resource use).

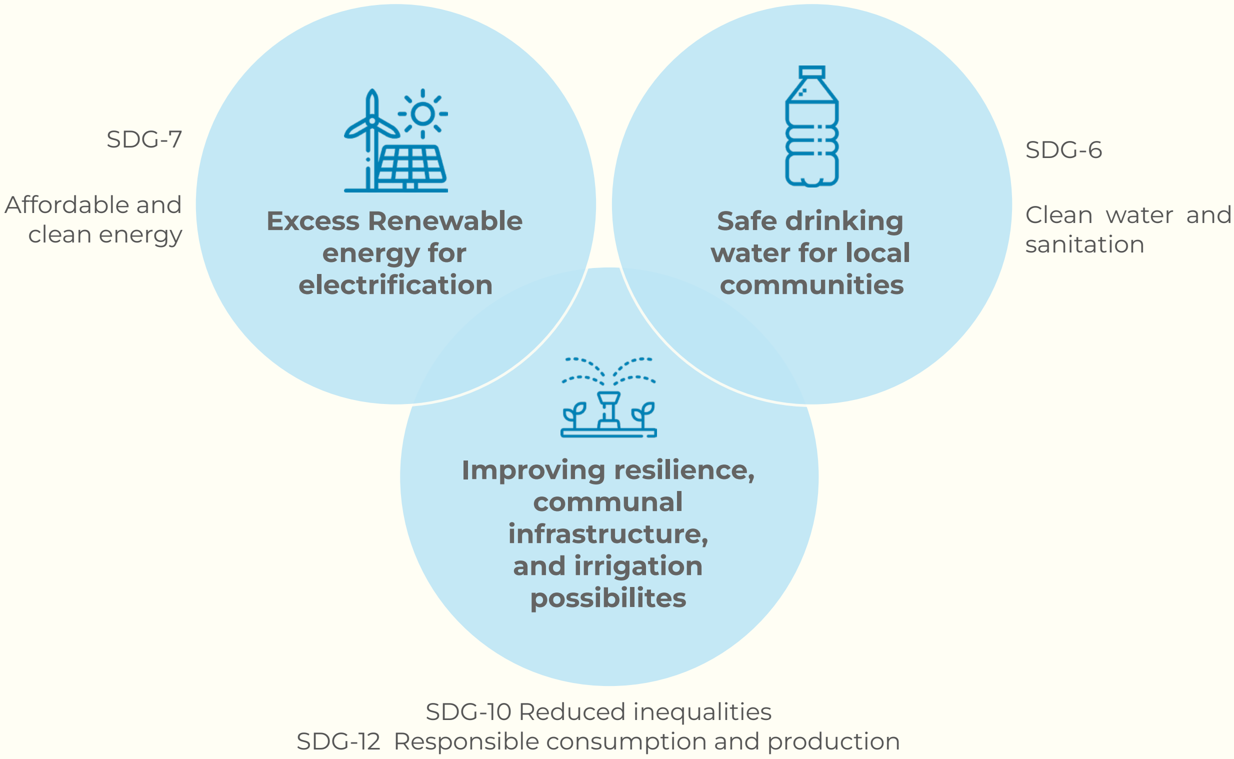


Figure - 12. Co-benefits of developing green hydrogen projects

Hydrogen production must be designed not only to avoid worsening water scarcity but also to actively contribute to water availability through strategic co-benefits. Incorporating desalination facilities within hydrogen projects, with additional capacity, can enhance local water supply for both domestic use and agriculture. Pakistan's prime RE zones, while optimal for wind and solar resources, face significant water stress with limited access to potable water and inadequate water infrastructure. Strategic deployment of advanced desalination and water management systems can address these challenges while promoting inclusive development. As illustrated in Figure - 9, the modest desalination costs within the total project framework enable synergistic benefits for communities and enterprises.

In addition, project development enhances the site's infrastructure by incorporating road construction and expanding grid access. This could be a win-win situation for local communities and business owners. It will also help to alleviate the socio-economic conditions of vulnerable groups such as youth and women.

4.G - Governance and Policy Landscape

The transformation of the energy and industry landscape involves not only addressing technological and economic challenges but also maintaining a balance with global governance and long-term climate objectives. It is essential to develop thoroughly analyzed and implementable policy recommendations that meet national needs for a successful energy transition. Governance issues are crucial for sustainability assessments of hydrogen as well at both the public policy level and the corporate and project levels.

The decarbonized energy trade will lead to energy security and independence while meeting climate ambitions. Globally 62 countries have already established their national hydrogen roadmaps, strategies, or implementation plans while many are still in the exploration phase [37]. For Pakistan, the development of a national hydrogen strategy is critical to addressing the multifaceted governance dimension. The strategy should entail the country's broader energy transition goals.

4.1 A clear roadmap towards decarbonization

Global markets of green hydrogen and PtX will only emerge if supply and demand grow at a steady scale. Figure - 13 provides an overview of the path to a PtX industry relying on three key elements: expanding technology, building markets and demand, and encouraging investment and supply.

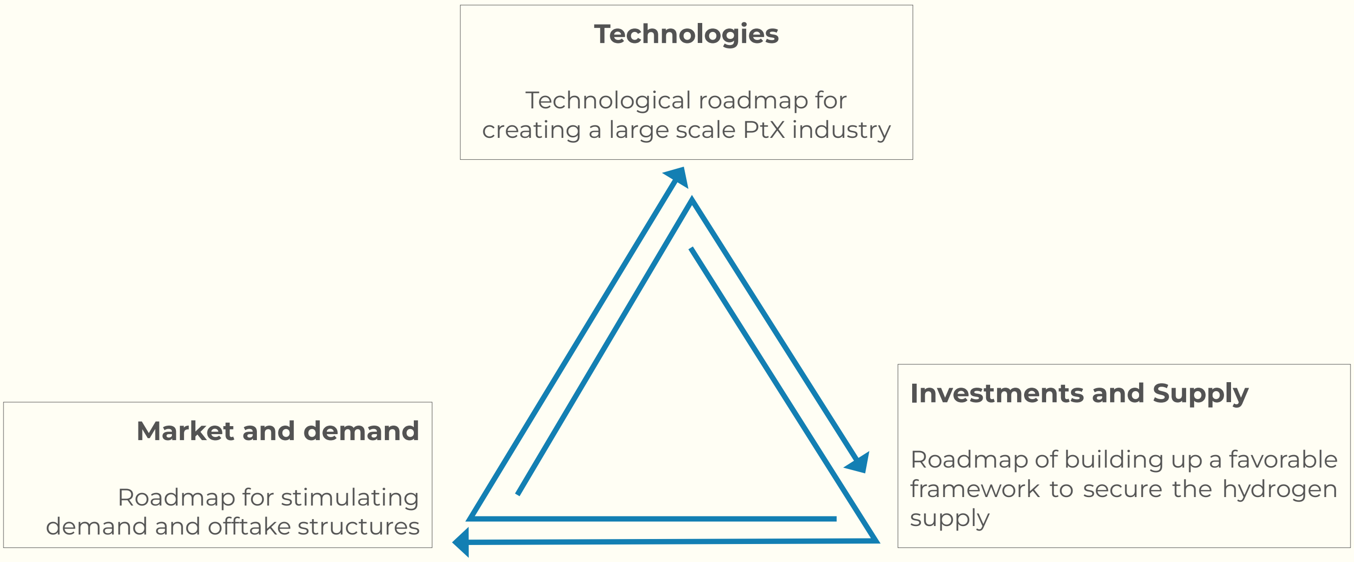


Figure - 13. Key drivers for developing an impactful hydrogen and PtX roadmap [38]

The "Technology" will play a pivotal role in defining economies of scale by providing a technological framework for building a large-scale hydrogen and PtX industry. The maturity of the hydrogen market will require advanced R&D efforts aimed at decreasing the cost of electrolyzers and enhancing their efficiency.

The development of a resilient hydrogen market demands a well-structured strategy to create investment certainty and drive project development forward. As global interest in green hydrogen and PtX products surges, potential supply constraints could emerge, highlighting the critical need for supportive investment frameworks that attract both private capital and international investments.

In the current scenario, accumulated energy import bills could be mitigated by using green electrolysis to curb the hydrogen demand. Given the country's fiscal constraints and the substantial upfront costs associated with green hydrogen technology, a strategic blend of private capital and concessional finance is essential to catalyze the hydrogen ecosystem. International cooperation would also emerge as a pivotal factor in this context mobilizing financial resources and fostering cross-border collaboration, accelerating the market's development, and ensuring its long-term viability.

4.2 Setting up realistic targets and preparing an actionable strategy

A successful hydrogen strategy needs realistic goals. Political and financial risks can prevent countries from maximizing their hydrogen production potential. Ideally, hydrogen ambitions could be embedded in NDCs that are pledged for climate commitments and Net-Zero roadmaps. The policy-making must consider not only technological and economic factors but also the geopolitical governance and security implications of changing energy supply and demand patterns.

Pakistan faces a challenging scenario with its ambitious pledge to unconditionally reduce 15% of GHG emissions by 2030 [21].This target should be integrated with the country's national RE goals. Policies need a clear and concise implementation roadmap to be impactful and effective. The failure to implement the Alternative Renewable Energy (ARE) 2019 policy highlights the lack of consideration for implementation during the policy development process.

Considering hydrogen as a key to decarbonizing hard-to-abate sectors highlighted in Box - 1, its role could only be defined by efficiently prioritizing its sectoral applications. Target setting process should include multistakeholder input to understand the local market needs and demand and supply mechanisms. A national vision would define how the strategy should either focus on meeting local demands or delving into the global trade market.

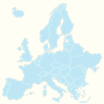
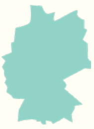
For global trade, considerations of various political and economic risks are integral to planning. These risks are quantified in the form of indexes such as the political stability index, the Gini coefficient, and the World Bank's **"Doing Business"** index. These parameters play a critical role in determining project viability. International policymakers and financial institutions use these indices to evaluate country risks for investment and policy decisions, while businesses rely on them to ensure sustainability standards.

4.3 Need for standardization and regulatory framework

Standardization is essential for implementing policies and establishing regulatory frameworks to eliminate risks of “Greenwashing”. These standards must offer clear guidance for investors, managers, and consumers. Without proper certification mechanisms, attracting investments and expanding functional markets is unattainable. Now, there is no global standard of what to be called “Green hydrogen” in terms of quantifying carbon emissions.

The existing global standards and certifications for hydrogen are developed by the private sector on a volunteer basis. Table - 4 details the existing schemes, most of them refer to the Guarantee of Origin (GO) to project developers for carbon reduction credibility of their projects.

Table - 4 Existing global standards and certification schemes for hydrogen (RFs compilation)

Country	Name	Type	Description
EU 	CertifHy	Certification	Voluntary GO scheme within the EU
France 	AFHYPAC	Certification	Voluntary GO scheme by French Association for Hydrogen & Fuel Cells
Germany 	TÜV SÜD	Certification	It is a voluntary standard for renewable hydrogen. There are two active certification programs: GO at the hydrogen production point or certification at the point of use, utilizing a mass balancing approach.
United Kingdom (UK) 	BEIS	Standard	UK Low Carbon Hydrogen standard (consultation process only)
United States (US) 	IPHE, LCFS	Initiative, Standard	International Partnership for Hydrogen and Fuel Cells in the Economy, Hydrogen Production Analysis (H2PA) Task Force5. Low Carbon Fuel Standard in California, USA
Australia 	Australian Government Scheme	Certification	Proposed certification scheme

Contrary to hydrogen certification scheme, ESG mechanisms are being established nationally to ensure adherence to sustainability aspects. Table - 5 provides a global overview of the existing and upcoming ESG mechanisms. The goal of ESG frameworks is to develop economically and socially responsible projects towards global development. They also set a pathway to decarbonize the economy by encouraging activities that are in line with the Net-Zero trajectory. Establishing and enforcing ESG regulations at the national level will impact financial flow and decision-making processes.

The Securities and Exchange Commission of Pakistan (SECP) has introduced voluntary ESG disclosure guidelines, aligning them with global ESG standards. These guidelines, although non-mandatory, aim to encourage transparency and promote adherence to the best international practices in environmental, social, and governance reporting [39].

Table - 5. Global ESG regulations landscape (RFs compilation)

Country	ESG Mechanism	Description
EU 	CSRD-Corporate Sustainability Reporting Directive	A strict standard will be implemented in 2022 and cover a broad range of companies operating in the EU.
	EU Taxonomy for Sustainable Activities	It classifies economic activities based on Net-Zero by 2050. It plays a key role in transparency and directing investments to sustainable projects.
	SFDR-Sustainable Finance Disclosure Regulation	This regulation was implemented in 2019 and influences financial products by integrating sustainability into investment decisions.
United State (US) 	Securities and Exchange Commission (SEC) Climate Disclosure rules	It was implemented in 2022 and mandates disclosing climate-related opportunities and risks.
	California Climate Disclosure Laws	It requires corporate giants to disclose their GHG emissions and have transparent ESG reporting.
United Kingdom (UK) 	SECR- Streamlined Energy and Carbon Reporting	This regulation requires companies to report their energy usage and carbon emissions, aiming to reduce carbon footprints, improve energy efficiency, and provide economic benefits. Companies consuming less than 40,000 kWh annually are exempt but must still declare their low energy use.
	Sustainability Disclosure Standards SDS	These standards, based on International Financial Reporting Standards (IFRS-SDS), will take effect at the beginning of 2025 to ensure consistency in global sustainability reporting.
	Disclosure Framework for Net-Zero Transition Plans	It is a framework for transparent reporting of climate-related risks and opportunities by companies. The framework is structured around four key pillars: governance, strategy, risk management, and metrics and targets.
Japan 	Corporate Governance Code	It encourages ESG consideration, and the Stewardship Code promotes responsible investments by institutional investors [40].
China 	National ESG rating system	To integrate environmental regulation into business, China is developing a national ESG rating system. These climate-related disclosure standards are set to be introduced by 2027 [41].
	Chinese sustainability Disclosure standards for Business	By creating a mandatory International Sustainability Board ISSB- China aims to establish a sustainability reporting system by 2030.

4.4 Government support and incentives

The government can ensure that accreditation and certification schemes adhere to internationally agreed quality standards. It could set up registries to monitor certified product quantities, GO, trade, and final product application. Third-party verifiers should audit the certificates in a project's life cycle. Certificates should be canceled once products reach their final users. This could only be effective if reliable schemes were established on a national level to guarantee product quality and facilitate market transfers.

a) financial incentives

To achieve economies of scale for hydrogen and its derivatives, considerable investments from both the private and public sectors are necessary. Due to the present capital intensiveness and market uncertainties, private investment will only happen if sufficient public support is available. This support can come in various forms, including investment grants and loans, Contracts for Difference CfD to bridge the price gap between supply and demand, quota and blending mandates, or public procurement programs.

Strict ESG regulations are gaining global momentum, they are resulting in comprehensive environmental and social impact assessments for financial investments. Many financial institutions have developed comprehensive guidelines for identifying risks and ensuring compliance with environmental, social, and governance standards. These guidelines also include governance measures related to public consultation or obtaining prior consent from affected stakeholders and communities.

Box - 7. Citizen's Energy

To facilitate energy transition Germany actively engaged its citizens by providing them with ownership of the renewable energy installations. The Renewable Energy Act (EEG), enacted in 2000, guaranteed fixed feed-in tariffs for those generating renewable power for 20 years period. This legislation further motivated households to install PV panels on their roofs, allowing them to feed electricity onto the grid or use it themselves.

Legal frameworks such as Energiegenossenschaften (Energy cooperatives) and hybrid "GmbH & Co. KG" (limited liability company & limited partnership) provided ownership to citizens to be part of large-scale installations that would be too costly for individuals to fund on their own. This enabled citizens to participate in energy transition while providing them with ownership of assets on fixed dividends. By 2017 this led to 31% ownership of private individuals and 10.5% of farmers in overall renewable energy power generation capacity [43].

4.5 Shaping Pakistan's hydrogen strategy

Pakistan's national hydrogen strategy needs to consider a multistakeholder approach. The energy transition will only succeed if all relevant stakeholders are not just informed but also actively involved in the process and empowered. Clear and concise regulatory frameworks are also necessary to ensure the sustainability of PtX products, projects, and policies. Here are a few considerations that could help to strategize the development of hydrogen and PtX roadmap and strategy:

a). Smart target setting

Pakistan should set transparent and realistic targets for green hydrogen production and trade, integrating a hydrogen strategy into its energy transition plan. This strategy should include measurable targets, clear priorities, and scenarios for renewable electricity capacity required for green electrolysis, supporting energy diversification. Hydrogen projects must align with national industrial and energy policies and contribute transparently to the country's energy transformation.

b). Legal and regulatory framework

A clear legal and regulatory framework is essential for the hydrogen industry's growth, addressing stakeholder needs and mitigating investment risks. Absence of a consistent regulatory framework presents a critical bottleneck in the developing interest of a wider audience. This is particularly important to mitigate the business risk associated with project development. Investors are less likely to be attracted to a country that has no or limited regulations.

To facilitate market development, a One-Window service for key players such as investors, developers, and policymakers—should be established, supported by a national strategy with monitoring mechanisms. This approach will attract investment and foster international collaboration, crucial for the success of hydrogen initiatives.

c). Stakeholders need assessment and engagement

The hydrogen strategy should incorporate extensive and transparent consultative engagement with all stakeholders. Governments and investors need to be engaged while making development policies to ensure the long-term success of decarbonization initiatives.

Stakeholder involvement can be integrated directly into the regulatory framework for effective planning and implementation phases. For this, local governments or policymakers could help facilitate dialogue between project developers and stakeholder groups. The potential for public-private partnerships should also be considered in stakeholder mapping. When creating standards and regulations, it is important to clarify how compliance will be monitored and enforced. Figure - 14 represents stakeholder mapping that could influence development of a strategy.

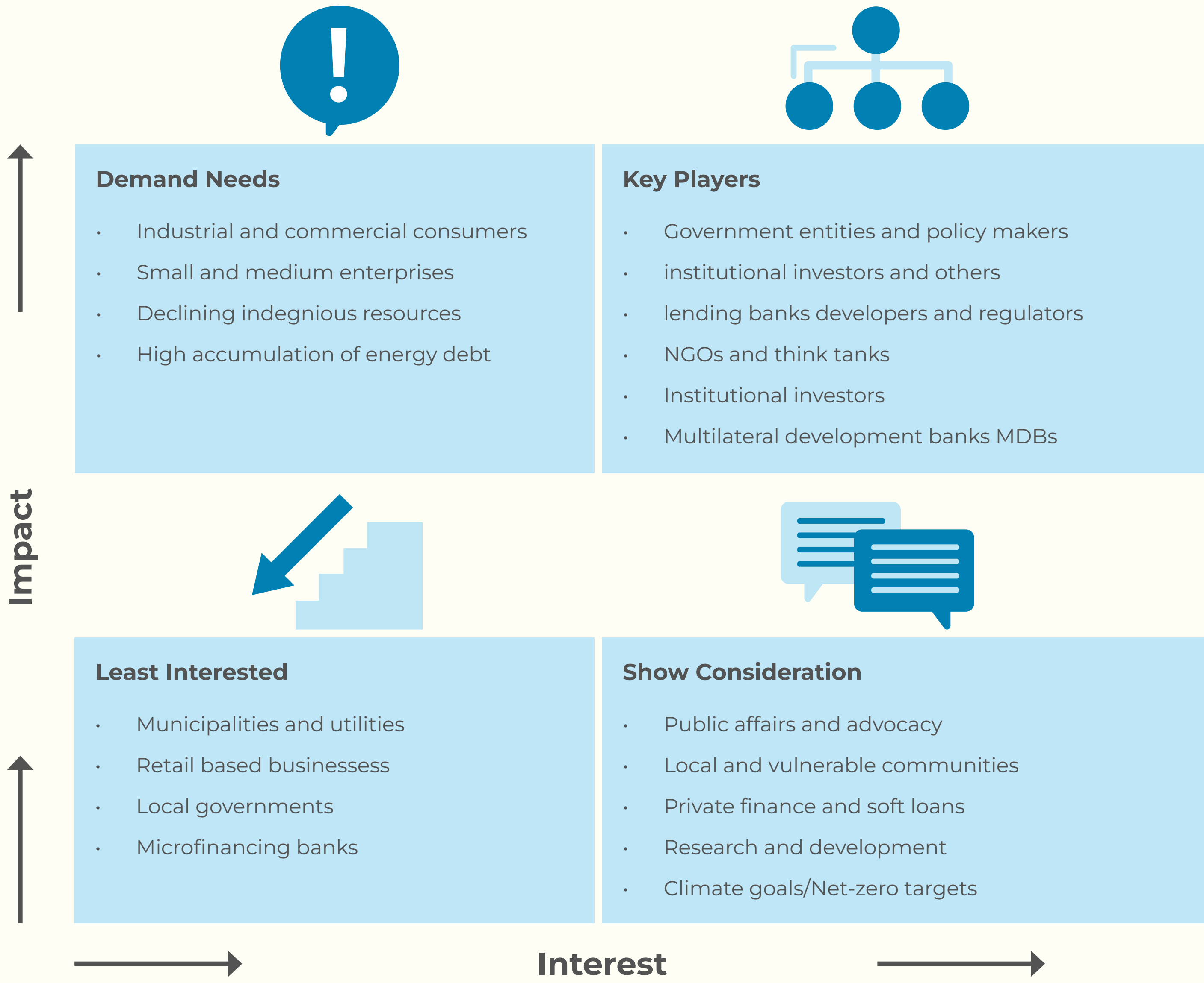


Figure - 14.Stakeholder analysis for green hydrogen projects in national context

d). Redirecting investments from fossil fuels

Global hydrogen investments are projected to reach USD 9 T by 2050, with USD 3.1 T of that expected to be directed towards developing economies [2]. This presents a significant opportunity for developing countries such as Pakistan to capitalize on its RE resources to attract foreign investments. Governments and private investments can reallocate financial resources from oil and gas to green hydrogen.

Alongside a circular debt of approximately USD 9.3 B the debt from gas imports has risen to USD 10.3 M [9]. This situation is particularly critical as major consumers include thermal power plants, fertilizer and cement industries, transport, and residential sectors. The overall scenario is dire, necessitating consideration of alternatives for long-term energy and food security.

e). Incentivization and tax rebates

Tax credits and subsidies could enhance the cost-competitiveness of modern technologies. However, this would require a thorough analysis of the country's financial landscape, thus proposing a suitable financial instrument to facilitate hydrogen transition. For example, mechanisms like Production Tax Credits (PTCs) and Investment Tax Credits (ITCs) have been proven beneficial in the US to attract investors by incentivizing them through production and infrastructure tax reductions. The USA Inflation Reduction Act (IRA) introduced the 45V Hydrogen Production Tax Credit, offering up to USD 3 per kg of hydrogen produced for projects that achieve a lifecycle GHG emissions intensity of less than 0.45 kg of CO2 equivalent per kg of hydrogen (kg CO2e/kg H2) [43].

Direct financial support through subsidies and grants are particularly important for early-stage projects for market proliferation. Furthermore, import duty exemptions on hydrogen-related technologies can also help to lower the costs of establishing infrastructure. Moreover, CfDs have been proven useful to de-risk investments by guaranteeing fixed prices for green hydrogen (for more understanding of CfDs in the hydrogen ecosystem refer to Box - 2), covering the gap between market prices and production costs. These incentives and tax rebates can reduce economic barriers, making green hydrogen a more attractive option for energy producers, consumers, and investors. Public procurement or auctions, and public-private partnerships could also be effective options for rapid market transition.

f). Market penetration and de-risking offtake agreements

Hydrogen and its derivative market already exist for its industrial consumers, contributing to 17% of current global carbon emissions [44]. Cost competitiveness of green hydrogen with grey and blue are currently debatable. Green hydrogen needs a significant reduction in the capital expenditure of electrolyzers and the cost of RE to achieve favorable costs.

Government could facilitate offtake alliances to secure consistent demand through long-term agreements with the industrial stakeholders. Long-term contracts could significantly reduce availability risks and ensure price stability. Collaboration among governments, developers and industrial stakeholders can help to establish a supportive market framework for growth. This collaboration can rapidly facilitate the scaling up of production capacities and the development of an integrated green hydrogen value chain.

g). Tapping into climate and carbon finance

On a national level, green hydrogen offers a chance to access climate finance. Given hydrogen's essential role in green industrialization and its broader impact on the energy transition, the substantial capital costs can be mitigated by emphasizing the necessity of climate action, which is more cost-effective compared to the consequences of inaction. Countries that are highly vulnerable to climate change, like Pakistan, could leverage climate finance for loss and damage to advance green hydrogen projects.

Integrating carbon credits and trading schemes can monetize the environmental benefits of green hydrogen, creating an additional revenue stream for producers through carbon markets. More details can be found in Section 1.5 and Box - 2.

h). Mitigating socio-political risks

For both domestic and international investment decisions, political stability, adherence to the rule of law, and addressing regulatory needs are crucial factors. This requires the establishment of strong ESG regulations and criteria that should be integrated with the planning phase to address the social and governance concerns. Nationally, this risk could be mitigated by a consistent policy and regulatory framework that addresses all stakeholders' needs. Furthermore, mechanisms such as public-private partnerships, where the government may act as a sovereign guarantor, or employ financing instruments like blended finance, which allocates risk across multiple financial institutions.

Conclusion and recommendations

Ensuring sustainability in all dimensions of development is critical for a just energy transition and equitable development. The EESG framework enables the development of hydrogen and PtX economy centered on people, products, and policies.

Focused policy support for green hydrogen ensures that initial projects, including pilot initiatives and early-stage developments, can compete fairly, gain market entry, and drive economies of scale. Strong policy support can accelerate the clean hydrogen economy's growth and ensure that it fulfills its critical role in achieving climate neutrality. The Net-Zero transition necessitates considering a broad vision of hydrogen and its derivatives, especially for hard-to-abate sectors, where hydrogen holds significant potential to decarbonize high-emission industries.

National strategies should prioritize diversification across the entire value chain—from trade partners to equipment and raw material suppliers—to prevent costly bottlenecks during scale-up thus enhancing market resilience. Significant public investment could also be allocated to infrastructure development, including the design of gas pipelines, shipping routes, and storage facilities for renewable hydrogen commodities. Governments can pursue international cooperation to align energy, climate, and development policies, while enhancing G2G bilateral trade agreements.

Policymakers can deploy targeted instruments, such as mandates, direct subsidies, CfDs, fiscal incentives, and public guarantees, towards establishing a hydrogen-based product market. The instruments could be beneficial to minimize the cost disparity between green and fossil-based grey hydrogen, at an initial stage. Furthermore, long-term offtake mechanisms can play a critical role in mitigating project risks, bridging the gap between market prices and creating cost competitiveness.

Sustainability in green hydrogen projects under the EESG framework requires a comprehensive approach to address upcoming challenges, as it is essential for achieving global sustainability goals. While ESG disclosures in Pakistan are anticipated to become part of national guidelines, they remain voluntary for now. Additionally, a hydrogen strategy is in progress, aiming to ensure these projects contribute to a wide range of SDGs and support Pakistan's NDCs. For a broad range of action, some key recommendations are:

Economics

- **Prioritizing green hydrogen can pave the way for energy independence while enhancing the economic aspect of sustainability**

In the economic aspect of the EESG framework, advancing green hydrogen projects leverages Pakistan's RE resources. This approach could help mitigate the rising circular debt while promoting energy independence and strengthening Pakistan's resilience against fluctuations in the global energy market. Hydrogen projects can stimulate economic growth, generate employment, and advance sustainability while aligning with Pakistan's RE goals.

Developing a local hydrogen supply chain is also crucial for economic growth. By prioritizing domestic production, distribution, and use of hydrogen, Pakistan can reduce reliance on imported RE equipment, stimulate the economy, improve cost competitiveness, and support local businesses.

- **Leveraging green hydrogen trade can boost economic growth and inter-regional energy cooperation in Asia**

Pakistan can position itself as a key producer of green hydrogen, supplying to countries like Japan, South Korea, and Thailand that are projected to be in the import spectrum of hydrogen needs in Net-Zero by 2050 scenarios. By exporting green hydrogen, Pakistan can attract foreign investment, create jobs, and enhance regional energy cooperation. For further information refer to Exhibit - 5. The regional trade would also facilitate technology transfer and infrastructure development, such as hydrogen pipelines and storage systems, strengthening Pakistan's role in Asia's hydrogen supply chain.

Environment

- **Implementing carbon emission caps in industrial sectors can boost clean alternatives adoption and advance Pakistan's climate goals**

There could be a significant decrease in industrial emissions by utilizing green hydrogen and its derivatives. Introducing carbon emission caps in Pakistan's industrial sectors will stimulate demand for cleaner technologies, including green hydrogen and its derivatives. These caps would encourage industries, such as textile manufacturing, to transition their energy mix and adopt innovative solutions to meet international certification standards and stay competitive in global markets.

- **Exacerbating water-stressed regions can benefit from green hydrogen projects**

The water-scarce regions of Sindh and Balochistan could benefit from the desalination of water, which could be a mandatory component of green hydrogen projects to help tackle the region's water scarcity challenges. The cost of desalination of water is minimum as compared to the overall cost of the green hydrogen project.

Governance

- **Creating a hydrogen policy that meets the decarbonization needs of multiple sectors is essential for energy transition**

A comprehensive decarbonization strategy is crucial for understanding green hydrogen needs for energy transition, facilitating carbon emissions reduction across multiple sectors. Policymakers must conduct comprehensive demand assessments to identify areas where grey hydrogen can be replaced with green hydrogen by promoting its adoption. Aligning hydrogen initiatives with broader decarbonization goals will enhance collaboration between public and private sectors.

- **Innovative hydrogen frameworks are being developed to support hydrogen and its derivatives, laying the groundwork for a thriving hydrogen market**

Globally, innovative frameworks are being developed to support the emerging market, as highlighted in Box - 3, which could help overcome market expansion challenges. The ammonia and methanol derivative markets are already well-established. Engaging with these derivative markets can foster collaboration among stakeholders, from producers to end-users, driving the creation of new business models and partnerships.

Social

- **The social dimension could help in enhancing local skills, capacity building and knowledge transfer**

Enhancing skills and building capacity within the workforce is also critical to support the hydrogen economy's growth. Investing in focused education and training programs can equip individuals with the technical expertise needed for hydrogen value chain and applications. Collaboration among government, industry stakeholders, and educational institutions can further ensure these programs align with market demands and facilitate knowledge transfer.

- **Hydrogen projects could provide multiple co-benefits including excess to safe drinking water and excess to RE**

From a social perspective, hydrogen projects provide numerous co-benefits, including access to clean drinking water, surplus RE for nearby areas, and electrification of rural communities. They also facilitate infrastructure improvements, such as roads and grid access, promoting inclusive development and supporting local communities, particularly vulnerable groups like women and youth.

Prospective areas for focus

This report outlines the broader sustainability aspects of hydrogen within a localized context. The forthcoming hydrogen strategy should thoroughly evaluate these sustainability criteria to create a practical implementation roadmap. Future efforts should prioritize the creation of a clear and concise legislative framework. This framework should incorporate a multi-stakeholder approach and consider the broader economic benefits to ensure a successful hydrogen strategy.

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Renewables First (RF) is a think tank for energy and environment. Our work addresses critical energy and natural resource issues with the aim to make energy and climate transitions just and inclusive.

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