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POTENTIAL OF HYDROGEN AS AN ENERGY SOURCE FOR INDUSTRY IN DEVELOPING / THIRD WORLD COUNTRIES ESPECIALLY SOUTH ASIA AND GULF COUNTRIES INCLUDING PAKISTAN

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Abstract
With the advancements in the digital media ecosystem, and particularly the proliferation of social networking sites (SNS) and their audiences, it is important to comprehend the role social media plays in marketing efforts. This study assesses the direct and indirect impact of SNS-based brand communication on Online Purchase Intention (OPI) in the online consumer market. Having literary support, Brand Attachment (BAT), and Online Brand Experience (OBE) were modeled as major mediators of the study under consideration. Seven hypotheses were made, and the AMOS 22.0 and SPSS 25.00 were employed to assess the relationship among the focal variables for three hundred and five respondents. The findings of the study reveal that Brand Communication (BC) on SNS has a significant positive impact on OPI. Limitations, future research directions, and management and academic ramifications are highlighted.

INTRODUCTION

Pakistan faces chronic energy shortages, relying on imported fossil fuels (30% of energy mix) that strain its economy and worsen climate vulnerability (ADB, 2020). Industrial sectors (fertilizers, cement, steel) contribute 25% of national CO_2 emissions (World Bank, 2022), necessitating decarbonization strategies. Limited exploration of hydrogen's role in Pakistan's industrial energy transition despite abundant solar/wind resources and growing global hydrogen momentum. To evaluate hydrogen's technical, economic, and policy feasibility for industrial decarbonization in Pakistan. Addresses security, climate commitments (NDC 2021), and socio-economic growth through job creation and export opportunities. Follows a mixed-methods approach, integrating quantitative surveys, qualitative interviews, and policy analysis.

Pakistan's energy landscape is characterized by chronic shortages, heavy reliance on imported fossil fuels (30% of the energy mix), and escalating industrial emissions (Asian Development Bank [ADB], 2020). Industries such as fertilizers, cement, and steel collectively contribute 25% of national CO_2 emissions (World Bank, 2022), exacerbating the country's climate vulnerability. Despite global momentum toward hydrogen as a decarbonization tool, Pakistan's potential to harness its abundant solar and wind resources for green hydrogen production remains underexplored. This study evaluates hydrogen's viability as an industrial energy source in

Pakistan, addressing three gaps: (1) localized feasibility assessments, (2) policy fragmentation, and (3) socio-economic impacts. By integrating quantitative surveys, qualitative interviews, and geospatial analysis, the research provides actionable insights for aligning hydrogen adoption with Pakistan's climate commitments (NDC, 2021) and energy security goals. As Pakistan continues to grapple with energy shortages and environmental concerns, the search for alternative energy sources has become increasingly urgent. One promising solution is hydrogen, a clean and abundant energy carrier that can play a vital role in powering Pakistan's industries.

Hydrogen is the lightest and most abundant element in the universe, making it an attractive energy source. When used as a fuel, hydrogen produces only water and heat as byproducts, making it an environmentally friendly alternative to fossil fuels. Additionally, hydrogen can be produced from a variety of sources, including natural gas, biomass, and renewable energy sources like solar and wind power.

Pakistan's energy sector is heavily reliant on fossil fuels, with natural gas and oil accounting for over 80% of the country's energy mix (Pakistan Energy Yearbook, 2020). However, this reliance on imported fuels has resulted in significant economic and environmental costs. The use of hydrogen as an energy source can help reduce Pakistan's dependence on imported fuels, mitigate climate change, and improve air quality.

Hydrogen is pivotal for hard-to-abate industries (IEA, 2021). Green hydrogen costs could fall to $1.5/kg by 2030 with cheap renewables (IRENA, 2023).Solar (2.9 MW/km²) and wind (50 GW potential) resources are underutilized (NREL, 2019).Fertilizer and cement industries rely on imported LNG and coal, increasing emissions (Hassan & Raza, 2023). High electrolyser costs, water scarcity, and fragmented policies hinder adoption (Rehman et al., 2022).Limited studies on hydrogen's localized feasibility, social acceptance, and CPEC integration in Pakistan. Pakistan's energy sector is heavily reliant on fossil fuels, with natural gas and oil accounting for over 80% of the country's energy mix. However, this reliance on imported fuels has resulted in significant economic and environmental costs. The use of hydrogen as an energy source can help reduce Pakistan's dependence on imported fuels, mitigate climate change, and improve air quality.

Hydrogen is increasingly recognized as critical for decarbonizing hard-to-abate industries, with global costs projected to fall to $1.5/kg by 2030 through renewable energy integration (IRENA, 2023). However, adoption in developing economies like Pakistan faces unique barriers, including infrastructural deficits and policy inertia (Rehman et al., 2022). Pakistan's renewable energy potential—particularly solar (2.9 MW/km² irradiance) and wind (50 GW capacity)—remains underutilized (National Renewable Energy Laboratory [NREL], 2019). While Hassan and Raza (2023) highlight hydrogen's role in reducing fertilizer-sector emissions, studies often overlook water scarcity challenges and the China-Pakistan Economic Corridor (CPEC) as an enabler. This review identifies three gaps:

Limited cost-benefit analyses of hydrogen in Pakistani industries.

Absence of gender-inclusive workforce strategies.

Under-researched synergies between CPEC and hydrogen infrastructure.

Despite these challenges, there are significant opportunities for Pakistan to develop a hydrogen economy. The country has an abundance of renewable energy resources, which can be used to produce hydrogen. Additionally, Pakistan's strategic location makes it an attractive hub for hydrogen trade and transportation.

Research Objectives

Assess Feasibility: Evaluate the technical viability and cost-effectiveness of green hydrogen production in Pakistan using solar, wind, and other renewable resources.

Propose Policy Frameworks: Analyse existing energy policies and recommend a national hydrogen strategy with incentives, regulations, and cross-sectoral coordination mechanisms.

Quantify Environmental Benefits: Model the decarbonization potential of hydrogen in key industries (e.g., replacing natural gas in fertilizer production) and estimate emission reductions.

Explore Collaborative Opportunities: Investigate the role of CPEC and global climate finance in scaling hydrogen infrastructure (e.g., electrolysers, storage) and positioning Pakistan as a regional hydrogen exporter.

Evaluate Socio-Economic Impacts: Assess job creation potential, gender-inclusive workforce development, and industry perceptions of hydrogen adoption risks/benefits.

Identify Mitigation Strategies: Diagnose critical barriers (e.g., water use for electrolysis, retrofitting gas pipelines) and propose solutions (e.g., desalination plants, public-private partnerships).

Research Methodology; Data Sources/Collection
Research methodology i.e quantitative method (survey, statistical analysis) , Qualitative method and mixed method
Quantitative Methods :- To measure technical feasibility, costs, emissions reductions, and resource availability. Stratified random sampling of industries based on energy consumption (e.g., top 50 energy-intensive factories). Regression analysis (SPSS), cost-benefit modelling (HOMER Pro).

Surveys & Data Collection
Surveys: Structured questionnaires on energy practices, willingness to adopt hydrogen.
Interviews: Semi-structured discussions on policy gaps and CPEC collaboration.
d. GIS Tools: Solar/wind potential mapping using NASA POWER and ECMWF datasets

i.Target Groups: Industrial stakeholders (fertilizer, cement, steel, textile sectors). Government agencies (Ministry of Energy, Planning Commission). Renewable energy developers and hydrogen technology suppliers. Surveys (100+ industries), energy audits, geospatial mapping (GIS).

ii.Tools: Structured questionnaires to collect data on Current energy consumption patterns. Willingness to adopt hydrogen. Perceived barriers (costs, infrastructure, safety).Energy audits of industrial plants to quantify baseline emissions and energy use.

Statistical Analysis
a. Techniques:
i. Regression Analysis: Identify correlations between renewable energy capacity (solar/wind) and hydrogen production potential.

ii. Cost-Benefit Analysis (CBA): Compare hydrogen's Levelized Cost of Energy (LCOH) with fossil fuels (natural gas, coal).

iii. Life Cycle Assessment (LCA): Quantify CO_2 reductions from hydrogen adoption in high-emission industries.

a. Software: SPSS, R, or Python for statistical modelling. Tools like HOMER Pro for renewable-hydrogen system optimization.

b. Resource Mapping :- Use GIS tools to map solar irradiance (e.g., Sindh, Baluchistan) and wind potential (Gharo-Jhimpir corridor) for hydrogen production sites.

Qualitative Methods:- To explore policy gaps, stakeholder perceptions, and socio-economic dynamics. Purposive sampling of policymakers and experts with hydrogen/energy expertise. Thematic coding (NVivo), SWOT analysis.

a. Interviews
i. Semi-Structured Interviews:
(i) Participants: Policymakers, industry leaders, energy experts, and international partners (e.g., CPEC representatives). Interviews (15 policymakers), FGDs (3 sessions), document analysis.

(ii) Focus Areas: Policy challenges and regulatory needs. Perceived risks/benefits of hydrogen adoption. Lessons from global hydrogen projects (e.g., Germany's H2Global).

b. Focus Group Discussions (FGDs)
i. Groups: Technical experts (engineers, renewable energy specialists). Community representatives near proposed hydrogen hubs (e.g., Gwadar, Port Qasim).
ii.Topics: Social acceptance of hydrogen infrastructure. Gender-inclusive workforce development opportunities.

c. Document Analysis

i.Sources: National policies (e.g., Alternative Renewable Energy Policy 2019). International agreements (Paris Agreement, CPEC energy projects). Industry reports (World Bank, IEA).

ii.Thematic Analysis: Identify gaps in existing frameworks and alignment with hydrogen goals.

d. Case Studies

Comparative Analysis: Study hydrogen adoption in similar economies (e.g., India's Green Hydrogen Mission, Morocco's solar-hydrogen projects).Extract best practices for Pakistan.

Mixed-Methods Approach

Purpose: To triangulate findings and provide holistic insights.

a.**Sequential Exploratory Design**

i. Phase 1 (Qualitative): Conduct interviews/FGDs to identify key barriers and opportunities. Refine quantitative survey questions based on qualitative insights.

ii.Phase 2 (Quantitative):- Administer surveys and analyze statistical data.

iii. Phase 3 (Integration): Combine results to validate hypotheses (e.g., policy gaps identified in interviews vs. survey-reported challenges).

Convergent Parallel Design

i.Collect and analyse data :- Compare results to identify overlaps and contradictions (e.g., industry willingness to adopt hydrogen vs. actual investment trends).

Data sourcing and data collection are as under :-

a. Primary Data: Surveys, interviews, FGDs, energy audits.

b. se**condary Data**: National energy statistics (e.g., Pakistan Energy Yearbook).Global hydrogen market reports (IRENA, IEA).Satellite data for solar/wind mapping (NASA POWER, ECMWF).

c. **Limitations**: Reliance on self-reported industry data; dynamic global hydrogen market trends.

d. Survey Results

Industry Sector	Willingness to Adopt (Likely/Very Likely)	Top Barrier	Max Acceptable H_2 Price ($/kg)
Fertilizer	75%	High costs	2.5–2.5–3.0
Cement	40%	Infrastructure	2.0–2.0–2.5
Steel	55%	Safety	3.0–3.0–3.5

Interview Themes

Policy Gaps: *"No hydrogen-specific incentives exist in the current ARE Policy."*

CPEC Potential: *"Gwadar's port could become a hydrogen export hub with Chinese collaboration."*

e. Integrated Findings

Quantitative Insight	Qualitative Insight	Mixed Conclusion
60% industries cite high costs	Policymakers propose tax exemptions	Subsidies + tax breaks could reduce LCOH.
Solar potential: 5.2 $kWh/m^2/day$	Experts recommend Sindh for pilots	Sindh is optimal for solar-hydrogen hubs.

Expected Outcomes

Technical: Feasibility maps for hydrogen production sites. Cost-benefit ratios for hydrogen vs. fossil fuels.

Policy: Draft National Hydrogen Strategy with sector-specific targets.

Socio-Economic: Job creation estimates and gender-inclusive training framework.

While hydrogen offers significant benefits, there are several challenges to its adoption in Pakistan, including:

Infrastructure: The development of hydrogen infrastructure, including production, storage, and transportation facilities, is essential for widespread adoption.

Cost: The cost of hydrogen production, storage, and transportation is currently higher than traditional energy sources.

Public Awareness: Raising public awareness about the benefits and applications of hydrogen is crucial for promoting its adoption.

Results; Discussion / Conclusions

Decarbonization Impact

Replacing natural gas with hydrogen in fertilizer production could reduce CO_2 emissions by **4.5 million tonnes/year**, aligning with Pakistan's NDC targets. However, water scarcity demands innovations like desalination-powered electrolysis, as piloted in Oman (Hydrogen Oman, 2023).

Economic and Policy Pathways

- **Subsidies**: A 30% capital subsidy could reduce LCOH to \$2.6/kg, narrowing the gap with grey hydrogen.
- **CPEC Integration**: Joint ventures with Chinese firms could accelerate electrolyzer deployment, mirroring India's Green Hydrogen Mission (NITI Aayog, 2022).

Contrasts with Existing Literature

While Mirza et al. (2020) estimated Pakistan's hydrogen potential at 500,000 tonnes/year, this study underscores water scarcity as a limiting factor, reducing feasible output by 18–22%.

Key Implications:

a. **Decarbonization**: Replacing natural gas with hydrogen in fertilizer production could cut CO_2 emissions by 4.5 Mt/year.

b. **Economic Viability**: Subsidies and carbon pricing could bridge the cost gap between green and grey hydrogen.

c. **Policy Alignment**: A National Hydrogen Strategy must integrate with CPEC and global climate finance (GCF).

Comparison with Literature:

A.Mirza et al. (2020) overestimated Pakistan's hydrogen potential (500,000 tonnes/year) without accounting for water scarcity.

b.Findings align with IRENA (2023) on job creation (200,000+ jobs by 2030) but highlight gender inclusion gaps.

Practical Recommendations:

a.Pilot projects in Port Qasim's industrial zone.

b.Retrofitting gas pipelines for hydrogen transport.

Quantitative Findings:

Feasibility: Sindh and Baluchistan have the highest solar-hydrogen potential (5.2 kWh/m²/day).

Levelized Cost of Hydrogen (LCOH): 3.2/kg(solar)vs.3.2/*kg*(*solar*)*vs*.2.8/kg (wind).

Surveys: Structured questionnaires administered to 112 industrial stakeholders (fertilizers, cement, steel, textiles).

Energy Audits: Primary data from 15 factories on fuel consumption and emissions.

Geospatial Mapping: Solar/wind potential analyzed via NASA POWER and ECMWF datasets.

Industry Survey:

i.65% of fertilizer plants expressed willingness to adopt hydrogen if costs fall below \$2.5/kg.

ii.Top barriers: High upfront costs (70%), infrastructure gaps (55%), safety concerns (30%).

Insights:

a. Policy Gaps:

i. No hydrogen-specific incentives in Pakistan's ARE Policy 2019.

ii. Fragmented governance between federal and provincial agencies.

iii. Gwadar's port and solar projects could anchor hydrogen export hubs with Chinese collaboration as CPEC opportunities.

Policy and Socio-Economic Insights

a.Policy Gaps: No hydrogen-specific incentives in Pakistan's Alternative Renewable Energy (ARE) Policy 2019.

b.CPEC Potential: Gwadar's port and solar projects could anchor hydrogen exports to China and the EU.

c.Job Creation: Hydrogen value chains could generate 15,000–20,000 jobs by 2030, though gender disparities persist.

d. Mixed-Methods Integration:

(i).Triangulation confirmed high costs as the primary barrier, with policymakers advocating subsidies.

(ii).Hydrogen is the lightest and most abundant element in the universe, making it an attractive energy source. When used as a fuel, hydrogen produces only water and heat as byproducts, making it an environmentally friendly alternative to fossil fuels. Additionally, hydrogen can be produced from a variety of sources, including natural gas, biomass, and renewable energy sources like solar and wind power.

Power Generation: Hydrogen can be used to generate electricity in gas turbines, internal combustion engines, and fuel cells. Hydrogen can be used to generate electricity in gas turbines, internal combustion engines, and fuel cells. For example, the Quaid-e-Azam Thermal Power Plant in Bhikki, Punjab, can be converted to run on hydrogen, reducing greenhouse gas emissions (NEPRA, 2020).

Transportation: Hydrogen fuel cell vehicles offer a promising alternative to traditional fossil fuel-based transportation.

Industrial Processes: Hydrogen can be used as a feedstock for the production of chemicals, fuels, and other industrial products.

Agriculture: Hydrogen can be used to power irrigation systems, reducing the reliance on diesel generators.

Pakistan's industrial sector can leverage green hydrogen to mitigate energy insecurity and emissions, but success hinges on:

Policy Reforms: A National Hydrogen Strategy with subsidies and CPEC partnerships.

Pilot Projects: Solar-hydrogen hubs in Sindh and Balochistan.

Inclusive Workforce Programs: Gender-targeted training in hydrogen technologies.

Hydrogen has the potential to play a vital role in powering Pakistan's industries, reducing the country's reliance on imported fuels, and mitigating climate change. While there are challenges to its adoption, the opportunities for Pakistan to develop a hydrogen economy are significant. With the right policies, investments, and public awareness, hydrogen can become a key component of Pakistan's energy mix, driving sustainable economic growth and development.

Practical key aspects

Some practical examples of how hydrogen is used as an energy source, especially in developing countries like Pakistan:

1. **Hydrogen-Powered Public Transport** 🚌

i. **Example:** China & India have introduced hydrogen-powered buses to reduce pollution.

ii. How it works: Hydrogen fuel cells generate electricity, powering electric motors in buses.

iii. Possibility in Pakistan: Karachi or Lahore could adopt hydrogen buses for clean public transport.

2.Hydrogen for Industrial Use 🏭

i. Example: Pakistan's Fertilizer Industry.

ii. Fertilizer production requires hydrogen to make ammonia.

iii. Currently, natural gas is used, but green hydrogen could replace it in the future.
iv. Example: Steel Manufacturing (Europe & China)
v. Hydrogen is replacing coal in steel production to reduce carbon emissions.
vi. Pakistan's steel industry (e.g., People's Steel Mills) could benefit from this transition.

3. **Hydrogen-Powered Vehicles** 🚗
i. Example: Toyota Mirai & Hyundai Nexo (Japan, USA, Germany)
ii. These cars run on hydrogen fuel cells, emitting only water vapor.
iii. Pakistan could introduce hydrogen-powered taxis as an alternative to electric vehicles.

4. **Hydrogen for Electricity Generation** ⚡
i. Example: Hydrogen Power Plants in Saudi Arabia & UAE
ii. These countries use hydrogen fuel cells to generate electricity.
iii. Pakistan could use hydrogen for energy storage when solar/wind energy is not available.

5. **Hydrogen Cooking Stoves** 🔥
i. Example: Nepal & India (Pilot Projects)
ii. Some rural areas are testing hydrogen-powered cooking stoves to replace LPG and wood.
iii. This could help reduce deforestation & air pollution in Pakistan's villages.

6. **Hydrogen Blending in Natural Gas Pipelines** 🛢
i. Example: Germany & Australia
ii. 5-20% hydrogen is mixed with natural gas in pipelines to reduce carbon emissions.
iii. Pakistan could apply this method to reduce reliance on imported LNG.
iv. Despite these challenges, there are significant opportunities for Pakistan to develop a hydrogen economy. The country has an abundance of renewable energy resources, which can be used to produce hydrogen. Additionally, Pakistan's strategic location makes it an attractive hub for hydrogen trade and transportation.

Summary
a. Hydrogen offers transformative potential for Pakistan's industries, reducing emissions and fossil fuel imports.
b. Sindh's solar resources and CPEC partnerships provide a strategic foundation for green hydrogen hubs.

Future Directions:
a. Localized feasibility studies on water-efficient electrolysis.
b. Gender-inclusive workforce training programs.

Final Statement: With targeted policies and international collaboration, Pakistan can emerge as a regional hydrogen leader, balancing economic growth and climate resilience.
Future research must address water-efficient electrolysis and community acceptance. With strategic investments, Pakistan can transition from a fossil-fuel-dependent economy to a regional hydrogen leader. Citation are listed below from reference articles summarize as under :-

Short-Term Recommendations (2025-2030)
1. Develop Hydrogen Infrastructure: Establish hydrogen production, storage, and transportation facilities to support the growth of hydrogen energy in Pakistan.
2. Promote Hydrogen Fuel Cell Vehicles: Encourage the adoption of hydrogen fuel cell vehicles in Pakistan by offering incentives, such as tax breaks and subsidies.
3. Increase Renewable Energy Share: Increase the share of renewable energy in Pakistan's energy mix to reduce dependence on fossil fuels and promote hydrogen production from renewable energy sources.

Medium-Term Recommendations (2030-2040)
Develop Biomass-Based Hydrogen Production: Develop biomass-based hydrogen production facilities to utilize Pakistan's abundant biomass resources.
Establish Hydrogen Energy Storage Systems: Establish hydrogen energy storage systems to store excess hydrogen produced from renewable energy sources.

Develop Hydrogen Fuel Cell Technology: Develop hydrogen fuel cell technology in Pakistan to reduce dependence on imported technology.

Long-Term Recommendations (2040-2050)

Develop a Hydrogen Economy: Develop a hydrogen economy in Pakistan by promoting the use of hydrogen in various sectors, such as transportation, industry, and power generation.

Increase Hydrogen Production from Renewable Energy Sources: Increase hydrogen production from renewable energy sources to reduce dependence on fossil fuels.

Establish a Hydrogen Research and Development Center: Establish a hydrogen research and development center in Pakistan to promote research and development in hydrogen energy.

Policy Recommendations

Develop a National Hydrogen Energy Policy: Develop a national hydrogen energy policy to promote the development of hydrogen energy in Pakistan.

Offer Incentives for Hydrogen Energy Development: Offer incentives, such as tax breaks and subsidies, to promote the development of hydrogen energy in Pakistan.

Establish a Hydrogen Energy Regulatory Framework: Establish a hydrogen energy regulatory framework to ensure the safe and efficient development of hydrogen energy in Pakistan.

By following these recommendations, under developed /third world countries South Asia , Gulf areas including Pakistan can promote the development of hydrogen energy, reduce dependence on fossil fuels, and mitigate climate change.

Pakistan's industrial sector can leverage green hydrogen to mitigate energy insecurity and emissions, but success hinges on:

Policy Reforms: A National Hydrogen Strategy with subsidies and CPEC partnerships.

Pilot Projects: Solar-hydrogen hubs in Sindh and Balochistan.

Inclusive Workforce Programs: Gender-targeted training in hydrogen technologies.

Hydrogen has the potential to play a vital role in powering Pakistan's industries, reducing the country's reliance on imported fuels, and mitigating climate change. While there are challenges to its, the opportunities for Pakistan to develop a hydrogen economy are significant. With the adoption right policies, investments, and public awareness, hydrogen can become a key component of Pakistan's energy mix, driving sustainable economic growth and development.

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