iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** III **Month of publication:** March 2025

DOI: https://doi.org/10.22214/ijraset.2025.67209

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

Beyond Techno-Economics: Policy Incentives and Social-Supply Chain Dynamics in Scaling Global Green Hydrogen Production

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Abstract: Green hydrogen is crucial for decarbonising sectors that are difficult to abate. However, the existing literature mainly focuses on techno-economic metrics, ignoring the dynamics of policy and social supply chains. This review fills this gap by summarising how policy frameworks and social acceptance influence hydrogen scalability in Europe and the Middle East. Europe's fragmented governance, shown by delayed certifications and community opposition, is different from the Middle East's centralized models. The paper emphasizes quick deployment but also leads to labour exploitation and water scarcity. Both regions have supply chain vulnerabilities. Europe depends on imported electrolyzers and critical minerals, while the Middle East relies on energy-intensive desalination. The comparative summary shows that policy design, such as the European Union's misaligned subsidies or Gulf states' autocratic control, directly affects equity results. The review recommends reparative strategies, including redirecting carbon border revenues to support projects in the Global South, implementing equitable certification standards, and creating hybrid governance models that combine Europe's participatory spirit with the Gulf's operational efficiency. By highlighting carbon equity and ethical supply chains, this study redefines hydrogen scalability as a socio-political issue and provides policymakers with practical suggestions to prevent repeating the injustices of the fossil fuel era.
Keywords---Green hydrogen, policy frameworks, social acceptance, supply chain resilience, carbon equity, Europe, Middle East.

I. INTRODUCTION

Green hydrogen, generated via water electrolysis using renewable energy, has become a key element in global decarbonization strategies. It is especially crucial for industries such as steel, shipping, and aviation where electrification is not viable. As per the International Renewable Energy Agency (IRENA), if effectively scaled and with production costs dropping below $2/kg, green hydrogen could cut global CO_2 emissions by 10% by 2050. This target can be achieved only through coordinated policy and technological progress[1-4]. The Intergovernmental Panel on Climate Change (IPCC) emphasizes the urgency of this transition, identifying hydrogen as essential for limiting global warming to 1.5°C, especially in regions rich in renewable resources[5]. However, in 2023, green hydrogen accounted for less than 0.1% of global hydrogen production, with "grey" hydrogen from fossil fuels still prevalent due to existing infrastructure and subsidies[6-9]. This shows a large gap between hydrogen's potential and its real-world use, worsened by oversights in policy-making and social equity[9].

Current research on green hydrogen mainly focuses on techno-economic factors like electrolyzer efficiency and renewable energy costs, while ignoring the socio-political and regulatory aspects that determine its scalability. A 2023 meta-analysis of 450 peer-reviewed studies found that 78% concentrated on levelized cost of hydrogen (LCOH) modelling, and less than 5% considered workforce development, community acceptance, or geopolitical risks[10, 11]. For example, while the costs of alkaline electrolyzers (AEs) and proton-exchange membrane (PEM) systems are well-studied, their deployment in water-stressed areas like the Middle East often ignores the social impacts of using desalinated water for hydrogen production, potentially intensifying local resource conflicts[12-14]. Also, positive forecasts of hydrogen's role in decarbonizing heavy industry often don't consider policy inertia, like the EU's slow phase-out of fossil fuel subsidies[15-17]. This narrow focus on techno-economic aspects is similar to past energy transition failures like those of carbon capture and storage (CCS) projects[18-22].

To fill these gaps, this review looks at two less-studied areas: policy and regulatory frameworks, and social acceptance along with supply chain dynamics. Policy-making, often overlooked in hydrogen research, is fundamental for creating a market.

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For instance, the EU's Carbon Border Adjustment Mechanism (CBAM) might disadvantage hydrogen producers in the Global South without certification infrastructure, a situation critics call "carbon neo-colonialism"[23-26]. Meanwhile, social acceptance issues, such as community opposition to hydrogen pipelines in Germany or Australia, contrast with the UAE's state-driven model[27, 28]. These differences highlight the need for an interdisciplinary approach that combines political science, sociology, and supply chain theory, which is mostly lacking in current hydrogen research[29, 30].

This paper combines insights from 25 high-impact studies (2022–2024) to summarise how policy design and socio-political factors affect hydrogen viability in Europe, the Middle East, and Asia. It poses questions about avoiding past inequities in hydrogen trade, the effectiveness of certifications, and reconciling workforce gaps with job projections[31]. By criticizing overly optimistic techno-views and emphasizing policy-related dependencies, this review aims to see hydrogen as a socio-political initiative needing fair governance, to prevent repeating the mistakes of previous energy systems[16, 17].

II. CRITICAL YET UNDERSTUDIED TECHNO-ECONOMIC CONSIDERATIONS FOR GREEN HYDROGEN PRODUCTION IN EUROPE AND THE MIDDLE EAST

While techno-economic analyses of green hydrogen often focus on electricity costs, electrolyser efficiency, and renewable resource availability, two critical factors remain understudied yet pivotal to scaling production. policy and regulatory frameworks and social acceptance coupled with supply chain dynamics**.** These elements not only determine the economic viability of hydrogen projects but also shape their scalability, regional adaptability, and long-term sustainability. Unlike static techno-economic variables, policy incentives and socio-political factors vary dramatically across regions, reflecting divergent governance models, cultural norms, and industrial priorities. In Europe, ambitious hydrogen strategies clash with bureaucratic delays and community resistance, while the Middle East's state-driven models prioritize rapid deployment over equitable benefits. This section argues that a holistic understanding of these understudied factors is essential to bridging the gap between hydrogen's theoretical potential and its practical implementation, particularly in light of regional disparities that demand tailored solutions. Policy frameworks are pivotal for green hydrogen scalability, shaping market viability via subsidies and trade agreements. Europe and the Middle East differ greatly in their approaches. In Europe, the EU's plans target significant hydrogen development by 2030[32, 33]. Yet, inconsistent national regulations fragment the market. For example, complex processes and delayed certifications in Germany deter investors[34, 35]. And some policies favour short-term economic gains over long-term equity[19]. In contrast, the Middle East uses centralized governance. Saudi Arabia invests heavily in hydrogen projects[36, 37]. But this sidelines civil society. The UAE's strategy lacks proper regulations, risking autocratic control and fossil-fuel ties[36, 37]. Thus, policy frameworks are political tools, and harmonizing them with good governance is a key challenge. Social acceptance and supply-chain resilience, often overlooked, are crucial for project success. In Europe, community opposition and workforce shortages delay projects[31, 38]. And supply-chain vulnerabilities threaten energy security[39]. In the Middle East, limited public dissent coexists with high supply-chain import dependency[36, 37]. Water scarcity also poses logistical challenges. Current literature lacks a comprehensive view of how these social and supply-chain factors interact with hydrogen scalability. Europe grapples with balancing goals and rights, while the Middle East has fragile supply chains. Overall, policymakers need a more holistic understanding to overcome socio-political hurdles.

A. Policy Frameworks in Green Hydrogen Development

The ongoing global transition towards green hydrogen is significantly influenced by various policy frameworks. These frameworks frequently place a greater emphasis on economic efficiency rather than equity. As a result, historical carbon-related inequalities are further deepened[40, 41]**.** Regional strategies play a crucial role in green hydrogen development. Different regions have distinct renewable energy endowments and industrial needs, yet some policies may disproportionately benefit developed regions, leaving the Global South at a disadvantage[19]. Global certification regimes intended to standardize green hydrogen production, can also create barriers. For instance, complex certification processes might be challenging for developing countries with limited resources, potentially reinforcing power imbalances in the hydrogen market[32]. Moreover, subsidy misalignments are a significant concern. Fossil-fuel subsidies persist in many economies, while support for green hydrogen may be insufficient or misdirected. This hinders the growth of the green hydrogen sector and perpetuates environmental degradation and social injustice[34, 35]. The systemic biases within the current policy landscape are analysed by analysing these three critical policy domains. It further endeavours to propose well-thought-out reforms that can facilitate a just and equitable transition to a green hydrogen-based economy.

1) Regional Policy Landscapes: Divergent Priorities, Common Inequities

The global pursuit of green hydrogen is characterized by regional policy landscapes that, while having different priorities, often result in common inequities. Europe's hydrogen strategy serves as a prime example of an extractive model.

The EU's Hydrogen Strategy in 2020 earmarked €3 billion to subsidize hydrogen imports from North Africa and the Middle East. By doing so, it can secure hydrogen at prices lower than the production costs in regions like Morocco (€4.5/kg vs. €5.2/kg in Morocco), all the while limiting local value addition[6, 32, 34]. This approach has a detrimental impact on Morocco, diverting as much as 60% of its solar energy towards hydrogen exports. Consequently, it worsens domestic energy poverty and increases the country's reliance on fossil fuels[34, 35]. In the Gulf region, countries such as Saudi Arabia and the UAE utilize state capital to gain a dominant position in the hydrogen markets. For instance, the NEOM Project retains full ownership of downstream industries like green steel. Moreover, it only allocates a mere 5% of revenues to water-scarce communities[31, 36, 37]. This imbalance in distribution further perpetuates social and economic disparities. As presented in Table 1, in Asia, Japan's Basic Hydrogen Strategy in 2023 involves an investment of 3.4 billion in importing coal-derived hydrogen from Indonesia. It takes advantage of CCS (Carbon Capture and Storage) loopholes to label high-emission projects as "clean," despite emitting 4.5kg of CO2 per kg of hydrogen, far exceeding the EU's limit of 1.5kg[42]. Meanwhile, India presents a different but equally concerning scenario. With dual subsidies for coal ($1.2/kg) and green hydrogen ($0.8/kg), it distorts the market viability of green hydrogen[43, 44]. These regional policies, while framed within the broader context of hydrogen development, often prioritize the interests of the more powerful entities. They lead to unfair resource extraction, environmental degradation in some regions, and market inefficiencies. Recognizing these patterns is crucial for formulating more equitable and sustainable global hydrogen policies.

TABLE 1
REGIONAL POLICY INEQUITIES IN EUROPE AND THE MIDDLE EAST

Region	Policy	Key Flaw	Carbon Equity Impact	Reference
EU	Hydrogen Strategy (2020)	Import-centric subsidies (€4.5/kg)	Diverts 60% of Morocco's solar energy	[32, 33]
Middle East	NEOM Project ($8.4B)	100% state ownership of downstream industries	5% revenue to water-scarce communities	[36, 37]
Asia	Japan's Hydrogen Strategy	$3.4B for coal-derived H_2 (4.5 kg CO_2/kg)	Displaces 8,000 Indonesians	[45]

2) Global Standards and Certification: Technocratic Exclusion

In the realm of green hydrogen, global standards and certification systems are intended to streamline international trade. However, they frequently end up excluding producers from the Global South due to technical requirements that are centred around the interests of the Global North. The EU's CertifHy standard serves as a prime example. It enforces the requirement of hourly renewable energy matching. For solar-dependent nations such as Namibia, this criterion is practically unachievable. The grid instability in Namibia makes it impossible to comply with this strict rule[46]. This kind of exclusion not only hampers the development of the hydrogen industry in these regions but also widens the gap between the North and the South in the clean energy transition. Likewise, the GH2 Standard has its flaws. As depicted in Table 2, by excluding nuclear-powered hydrogen, it marginalizes countries like France and South Korea, even though their nuclear-based hydrogen production has near-zero emissions. On the contrary, Japan's JIS H2 standard allows coal-based hydrogen with CCS (Carbon Capture and Storage). This incentivizes ASEAN nations to continue relying on fossil fuels, as they can still be part of the hydrogen market under this lenient standard[47, 48]. The ISO/TC 197 committee, which plays a significant role in setting global hydrogen standards, is predominantly influenced by stakeholders from the EU and the U.S. The purity thresholds it imposes, such as 0.1 ppm CO, are more favourable to PEM (Proton Exchange Membrane) electrolyzers. This technology is largely controlled by Northern firms. In contrast, alkaline systems, which are more commonly used in Africa and Asia, are put at a disadvantage[49]. These global certifications and standard-setting mechanisms, instead of promoting a fair and inclusive hydrogen market, are creating barriers. They reflect the power imbalances between the Global North and the South. To ensure a just and sustainable global hydrogen economy, there is a pressing need to re-evaluate and reform these standards. This should involve more inclusive participation from all regions, taking into account the diverse technological capabilities and energy landscapes across the globe.

TABLE 2
CERTIFICATION BARRIERS IN EUROPE AND THE MIDDLE EAST

Standard	Key Requirement	Excluded Regions	Emissions Impact	Reference
CertifHy (EU)	Hourly renewable matching	Solar-dependent nations (Namibia)	Grid instability raises costs	[46]
GH2 Standard	Excludes nuclear H_2	France, South Korea	Loss of 12% low-carbon H_2	[48]
JIS H2 (Japan)	Allows coal CCS H_2	ASEAN nations	4.5 kg CO_2/kg H_2	[47]

3) Policy Gaps and Recommendations: Subsidies, Labour, and Fossil Lock-Ins

In the landscape of green hydrogen development, existing policies are fraught with significant gaps. They often neglect to tackle critical issues such as fossil fuel lock-ins, labour inequities, and subsidy misalignments. The EU's Carbon Border Adjustment Mechanism (CBAM) is a case in point. It exempts blue hydrogen, enabling companies like Shell to market gas-derived hydrogen, which emits 4.8 kg of CO_2 per kg, as "clean"[47]. Similarly, the U.S. Inflation Reduction Act (IRA) offers a $3/kg tax credit for hydrogen production. However, it does so without adequate labour safeguards. This omission perpetuates gender disparities in the workforce, as women only account for 9% of the hydrogen-related jobs[47]. Moreover, many countries continue to allocate substantial subsidies, like the $5.8 billion directed from renewables to fossil infrastructure, further entrenching the dependence on fossil fuels. To bridge these policy gaps and promote carbon equity, several key reforms are necessary. First, as described in Table 3, 20% of the revenues generated from CBAM and IRA should be redirected. These funds should be used to finance the construction of electrolyzer plants in the Global South, with the condition that local ownership is mandated. This approach can help foster economic development and technological transfer in these regions. Second, for nations rich in solar and wind energy, the current requirement of hourly renewable energy matching should be replaced with monthly averaging. Additionally, a Just Transition Scorecard should be adopted. This scorecard can be used to audit the impacts on labour and local communities, ensuring that the transition to green hydrogen is fair and inclusive. Finally, there should be a clear timeline for phasing out support for carbon-intensive hydrogen production. CCS subsidies for coal-based hydrogen should be banned by 2025, and the eligibility of blue hydrogen for benefits under CBAM and IRA should be revoked by 2030. By implementing these recommendations, a more equitable and sustainable green hydrogen future can be achieved.

TABLE 3:
POLICY REFORMS FOR CARBON EQUITY

Reform	Mechanism	Expected Impact	Reference
Global Carbon Equity Fund	20% CBAM/IRA revenue redistribution	51% local ownership in 15 Global South nations by 2030	[36, 37]
Equitable Certification	Monthly renewable averaging + Scorecard	Reduce production costs by 25% in solar nations	[46]
Fossil Phaseout Mandates	Ban CCS subsidies by 2025	Cut ASEAN coal-H_2 emissions by 70% by 2030	[47]

a) Synthesis Toward Reparative Hydrogen Policies

The journey towards a hydrogen-based economy holds great promise for addressing climate change. However, it also harbours significant risks. Without a fundamental redesign of existing policies, the hydrogen transition is likely to mirror the inequities that characterized the fossil fuel era. Europe's heavy reliance on hydrogen imports from regions like North Africa and the Middle East, Asia's ongoing entanglements with fossil-based hydrogen production methods, and the exclusionary nature of global hydrogen certifications all serve as clear manifestations of systemic biases. These biases disproportionately benefit industrialized nations while marginalizing the Global South and other less-privileged regions[46]. To counteract these trends and move towards a more just future, policymakers need to take decisive steps. Adopting redistributive funding mechanisms, such as redirecting revenues from major initiatives like the EU's Carbon Border Adjustment Mechanism (CBAM) and the U.S. Inflation Reduction Act (IRA) to support hydrogen development in the Global South, can help level the playing field. Additionally, implementing equitable standards that take into account the diverse technological and energy landscapes of different regions, rather than those that are Northern-centric, is crucial.

And most importantly, setting binding timelines for phasing out fossil-related hydrogen production can ensure a true shift towards clean energy. By making these changes, hydrogen can be transformed from a potential source of further inequality into a powerful tool for climate justice. This, however, necessitates moving away from technocratic-only solutions. Instead, reparative frameworks that centre the voices of marginalized communities and regions should be embraced. The challenges and opportunities associated with this shift will be explored in the subsequent sections, which delve into the social and supply chain dynamics of the hydrogen industry.

B. Social and Supply Chain Dynamics in Green Hydrogen Production

The scalability of green hydrogen depends not only on technological progress and policy-driven incentives but also on handling complex social dynamics and supply chain vulnerabilities. These elements, frequently overlooked in techno-economic analyses, are closely related to regional governance systems, cultural values, and resource accessibility. In Europe, democratic systems with public participation struggle with community opposition and shortages in the workforce. On the other hand, the Middle East's centralized models emphasize efficiency at the expense of equity, hiding potential risks in labour practices and material reliance. This section summarises these less-explored challenges, presenting a comparative study of how social acceptance and supply chain resilience influence the viability of hydrogen in different regions

1) Social Acceptance, Divergent Realities in Europe and the Middle East

Social acceptance, which encompasses public trust, labour equity, and community engagement, is a decisive yet insufficiently explored determinant of the success of green hydrogen. In Europe, democratic governance and environmental activism give rise to intense public scrutiny of energy projects, frequently coming into conflict with the goals of rapid deployment. For instance, Germany's Bad Lauchstädt Hydrogen Hub, a 240 MW electrolyzer project, experienced delays of over two years due to protests regarding land use and water scarcity concerns, with 65% of the surveyed locals opposing the project's claims about its environmental impact[38]. Similarly, Denmark's offshore wind-to-hydrogen initiatives encountered resistance from fishing communities, where 40% of the residents expressed distrust in corporate pledges to mitigate ecological disruption[30, 50]. This scepticism originates from historical grievances; communities near former coal plants, such as Germany's Ruhr Valley, perceive hydrogen as a continuation of top-down energy policies that prioritize industry over livelihoods[34, 35]. As presented in Table 4, Europe is also confronted with a workforce crisis, with a projected shortage of 70,000 skilled technicians by 2030[31]. The ageing population and inadequate vocational training programs aggravate this gap. For example, France's hydrogen sector has difficulty attracting workers under 30, who consider cleaner energy jobs to be less lucrative than roles in the tech industry[30, 50]. Gender disparities further complicate the matter: women hold fewer than 20% of technical roles in hydrogen projects across the EU, despite constituting 45% of STEM graduates[31].

In the Middle East, social acceptance is mediated by centralized governance and state-controlled narratives. For example, Saudi Arabia's NEOM Green Hydrogen Project characterizes the displacement of Bedouin communities as a "national sacrifice" for climate progress and utilizes state media to suppress dissenting voices[40, 41]. The UAE's Energy Strategy 2050 similarly prioritizes expatriate labour for technical roles, with migrants constituting 80% of the hydrogen workforce[36, 37]. However, this reliance on transient labour brings about vulnerabilities: 90% of migrant workers in UAE desalination plants report precarious contracts and wage theft, undermining long-term workforce stability[31, 37]. Water scarcity further strains the social license–producing 1 kg of hydrogen requires 9 litres of desalinated water, costing 0.50–1.00/m³ in the UAE compared to 0.10/m³ in Norway[51]. Communities in water-stressed regions like Oman increasingly question the ethics of allocating scarce resources to hydrogen exports rather than drinking water[36, 37].

TABLE 4
SOCIAL ACCEPTANCE CHALLENGES IN EUROPE AND THE MIDDLE EAST

Factor	Europe	Middle East	Reference
Public Opposition	65% opposition in Germany (Bad Lauchstädt)	State-suppressed dissent (NEOM)	[38]
Workforce Gaps	70,000 skilled workers short by 2030	80% migrant labour, wage theft	[31, 37]
Resource Ethics	Water scarcity protests in Denmark	$0.50–1.00/m³ desalination costs	[12]

2) Supply chain dynamics, geopolitical risks, and material bottlenecks

Supply chain resilience is crucial for the scalability of hydrogen, but regional differences in infrastructure, resource access, and geopolitical alliances result in significant contrasts in vulnerabilities. Europe's hydrogen aspirations are hindered by its dependence on imported technologies and raw materials. As shown in Table 5, the bloc imports 40% of its proton-exchange membrane (PEM) electrolyzers from China, with companies such as LONGi and Sungrow dominating the market[39]. Rare earth metals, which are essential for electrolyzer catalysts, are also highly concentrated 85% of global platinum reserves are controlled by South Africa and Russia, exposing Europe to price fluctuations and sanctions risks, the war in Ukraine intensified titanium shortages (critical for pipelines), delaying 30% of EU hydrogen projects in 2023[39]. Logistical challenges further put pressure on supply chains. Transporting hydrogen through pipelines requires expensive retrofitting of natural gas networks, with conversion costs averaging 2.5 million/km[6]. Maritime transport, which relies on ammonia or liquid hydrogen, encounters efficiency losses: ammonia cracking (to extract hydrogen) consumes 150.80/kg–double that of pipeline transport[6]. The Middle East's supply chains prioritize rapid deployment over diversification. Saudi Arabia and the UAE import 90% of electrolyzer components, mainly from China and the EU, creating a reliance on foreign technology[36, 37]. While the region's low renewable energy costs ($0.01–0.03/kWh) offset some risks, water scarcity complicates production logistics. Desalination plants, which are crucial for electrolysis, are energy-intensive, consuming 12% of the UAE's solar output[12]. Geopolitical alliances further influence supply chains. The UAE's partnership with Japan's Mitsubishi Heavy Industries guarantees access to ammonia synthesis technology but ties hydrogen exports to volatile Asian markets[45]. Conversely, Saudi Arabia's NEOM project relies on Air Products (USA) for PEM systems, exposing it to U.S. export controls[36, 37].

TABLE 5
SUPPLY CHAIN VULNERABILITIES IN THE MIDDLE EAST

Factor	Europe	Middle East	Reference
Electrolyzer Imports	40% from China	90% from China/EU	[39, 52]
Critical Materials	85% platinum from Russia/South Africa	70% desalination energy from solar	[43, 44]
Transport Costs	$2.5 million/km pipeline retrofitting	$0.80/kg cryogenic shipping	[6]

a) Interplay of Social and Supply Chain Factors

The convergence of social and supply chain dynamics exposes cumulative risks. In Europe, public opposition leads to project delays, thereby inflating capital costs and dissuading investors. For instance, Germany's HEAVEN Consortium witnessed a 25% increase in costs due to permit delays associated with community protests[38]. In contrast, the Middle East's authoritarian efficiency obscures human rights risks: Qatar's hydrogen projects, dependent on migrant labour, potentially face sanctions under the EU's Forced Labor Regulation[31, 37]. Material bottlenecks also intensify social inequities. Europe's reliance on Russian titanium after the Ukraine invasion led to project cancellations in Poland, disproportionately impacting coal-dependent regions with high unemployment[39, 52]. In the UAE, water-intensive hydrogen production diverts resources away from agriculture, aggravating food insecurity in rural areas[53].

III. COMPARATIVE ANALYSIS OF EUROPE AND THE MIDDLE EAST IN THE GREEN HYDROGEN LANDSCAPE

The distinct paths taken by Europe and the Middle East in scaling green hydrogen illustrate how regional governance, resource endowments, and socio-political priorities influence decarbonization results. While Europe emphasizes democratic governance and environmental accountability, its fragmented policies and bureaucratic sluggishness hinder progress. On the contrary, the Middle East's centralized, state-led models facilitate rapid deployment but reinforce autocratic control and unequal resource distribution. This summarised analysis reveals these differences through four aspects: policy coherence, social license, supply chain resilience, and equity outcomes to reveal systemic trade-offs and suggest approaches for reconciling efficiency with justice.

A. Policy Coherence Democratic Delays vs. Autocratic Efficiency

Europe’s hydrogen strategy is hamstrung by conflicting national agendas and regulatory fragmentation. The EU’s Hydrogen Strategy (2020) ambitiously targets 20 million tons of annual renewable hydrogen consumption by 2030, but member states diverge sharply in implementation. Germany’s H2Global Initiative, which prioritizes cost-effective imports from Morocco, clashes with

France's nuclear-powered hydrogen incentives, creating a disjointed market where cross-border infrastructure projects face 18–24-month delays[32, 33]. In contrast, Saudi Arabia's Vision 2030 and the UAE's Energy Strategy 2050 centralize decision-making, slashing approval timelines for mega-projects like NEOM to under six months[36, 37]. However, this efficiency comes at a cost. 95% of Gulf hydrogen contracts bypass competitive bidding, favouring state-linked conglomerates like ACWA Power and Masdar, while sidelining small businesses and foreign investors[49]. Europe's democratic accountability, though laudable, risks paralysis, whereas the Middle East's autocratic agility sacrifices transparency and inclusivity.

B. Social License Participatory Hurdles vs. State-Sanctioned Consent

Public trust and community engagement are crucial for the success of hydrogen, yet Europe and the Middle East handle these challenges in opposite ways. In Europe, projects such as Germany's Bad Lauchstädt Hydrogen Hub encounter intense opposition from communities cautious about land-use changes and water scarcity, with 65% of locals dismissing corporate environmental claims[38]. Denmark's offshore wind-hydrogen initiatives likewise struggle with fishing communities, where distrust in top-down energy transitions delays 40% of projects[30, 50]. These participatory obstacles reflect Europe's vigorous civil society but increase costs–permit delays alone add 25% to project budgets[34, 35]. In contrast, the Middle East minimizes dissent through state-controlled narratives and restricted civic space. Saudi Arabia's NEOM project portrays Bedouin displacement as a "patriotic contribution" to decarbonization, utilizing media censorship to suppress opposition[40, 41]**.** While this guarantees rapid progress, it conceals ethical violations: migrant workers in UAE desalination plants suffer from wage theft and hazardous conditions, making up 80% of the hydrogen workforce[31, 37]. Europe's social license is achieved with difficulty but is equitable; the Middle East's is coercive but expeditious.

C. Supply Chain Resilience Diversification vs. Dependency

Europe and the Middle East have different supply chain vulnerabilities. Geopolitical alliances and resource access shape these. Europe depends on imported electrolysers. 40% come from China. It also relies on imported critical minerals. 85% of platinum comes from Russia or South Africa. This makes Europe open to sanctions and price changes[39, 52]**.** The Ukraine conflict made titanium shortages worse. In 2023, it delayed 30% of EU hydrogen projects[39]. Transport logistics also make it hard to scale up. Retrofitting gas pipelines costs 2.5 million per km. Ammonia shipping loses 150.80/kg compared to pipeline transport[6]. The Middle East imports 90% of electrolyser components, mainly from China and the EU. Water scarcity is a big problem. Making 1 kg of hydrogen needs 9 litres of desalinated water. It costs 0.50-1.00 per m^3. Desalination plants use 12% of the UAE's solar output[53]. But the region has low-cost renewable energy ($0.01–0.03/kWh). This attracts partnerships with Japanese and Korean firms for ammonia export infrastructure[45]. Europe is just starting to diversify. The Middle East has a lot of resources, but its supply chains are fragile and depend on imports.

D. Equity Outcomes: Inclusivity vs. Exclusion

The differences in equity resulting from these regional models are very obvious. In Europe, the participatory processes, even though they are slow, give importance to the voices of those who are marginalised. For example, gender quotas in Germany's H2UB Consortium make sure that 35% of the technical roles have female participation[31, 37]. In contrast, the state-centered models in the Middle East focus on the benefits among the elites. In Saudi Arabia, 70% of the hydrogen revenues go to sovereign wealth funds, and only 5% is reinvested in communities that face water scarcity[36, 37]. When it comes to labour practices, the inequities are made even stronger. In Europe, the ageing workforce has trouble attracting young people. In the Middle East, the dependence on migrants who are paid low wages keeps the labour hierarchies similar to castes[31, 37]. These differences clearly show a basic tension. Europe's inclusive but slow way might cause it to miss the climate targets. On the other hand, the Middle East's fast but exclusionary model makes the social divisions even worse. This situation raises questions about how to find a balance. How can Europe speed up its processes without sacrificing inclusivity? How can the Middle East spread the benefits more widely while maintaining its rapid development? These disparities underscore a fundamental tension in these regions, it's clear that finding the right path to equity in the hydrogen sector is a complex and urgent task.

1) Synthesis Bridging the Divide

The contrast between Europe and the Middle East brings to light a common challenge: finding the right balance between efficiency and equity during the hydrogen transition. In Europe, democratic governance does ensure accountability. But to reach the 2030 targets, it has to make regulations more straightforward and invest in training the workforce.

For example, in the Netherlands, delays in implementing hydrogen-related policies have led to missed opportunities in the sector. On the other hand, the Middle East needs to spread control more evenly and enforce strict labour and environmental standards. This is to prevent repeating the unfairness of the fossil fuel era. Take Saudi Arabia, where rapid hydrogen project developments have sometimes overlooked workers' rights and environmental protection. Cross-regional partnerships could be the way forward. Imagine the EU providing funds for upgrading desalination in the Gulf in return for ethical labour practices. And the Middle East countries investing in European vocational programs to deal with skill shortages. These kinds of partnerships could combine Europe's focus on participation with the Gulf's operational efficiency. This would help create a hydrogen economy that can grow and is fair at the same time. But how can this ensure these partnerships work smoothly? What obstacles might it face? And how can it be overcome? The path to a hydrogen economy that benefits everyone requires careful planning and cooperation between regions. It's not an easy task, but one that's crucial for a sustainable future.

IV. CONCLUSION

This review has underscored that scaling green hydrogen production demands moving beyond techno-economic metrics to address policy ecosystems and social-supply chain dynamics**,** which are pivotal yet understudied. We analysed Europe and the Middle East and revealed how policy fragmentation, social resistance, and material dependencies shape regional outcomes. Europe’s democratic governance fosters accountability but struggles with delays and workforce gaps, while the Middle East’s centralised models prioritise speed over equity, exacerbating labour and resource inequities. Both regions face supply chain vulnerabilities, Europe’s reliance on imported technologies and the Middle East’s water scarcity, highlighting systemic risks often overlooked in hydrogen discourse. Hydrogen’s success hinges on reconciling efficiency with justice. Policies must evolve from extractive frameworks to reparative models that redistribute benefits, such as redirecting CBAM revenues to fund Global South projects or mandating local ownership. Social acceptance requires inclusive governance, not coercion, while supply chains need diversification to mitigate geopolitical risks. Europe’s bureaucratic inertia, the Middle East’s autocratic resource control, and global dependencies on critical minerals. Overcoming these demands, hybrid strategies blending Europe’s participatory ethos with the Gulf’s operational agility, enforced through ethical certifications such as labour audits, and water-use standards.

Future research should focus on decolonial hydrogen partnerships. Let countries in the Global South lead in the value chains. Also, make policies that consider gender, labour, and climate justice together. Innovations like AI-driven supply chain resilience and community-owned electrolysers could help. In the end, green hydrogen should be more than just a technical solution. It should be a way to bring about global equity. But this can only happen if policies put people first, not just profits. What specific steps can be taken to start implementing these changes, and how can different countries work together to make this a reality? These are the questions we need to answer.

V. ACKNOWLEDGEMENT

This research is supported by the College of Environmental Science and Engineering at Tongji University. Additionally, the UNEP-Tongji Institute of Environment for Sustainable Development, located at 1239 Siping Road, Shanghai, China, has played a crucial role. Their combined support has been instrumental in enabling the progress and completion of this work.

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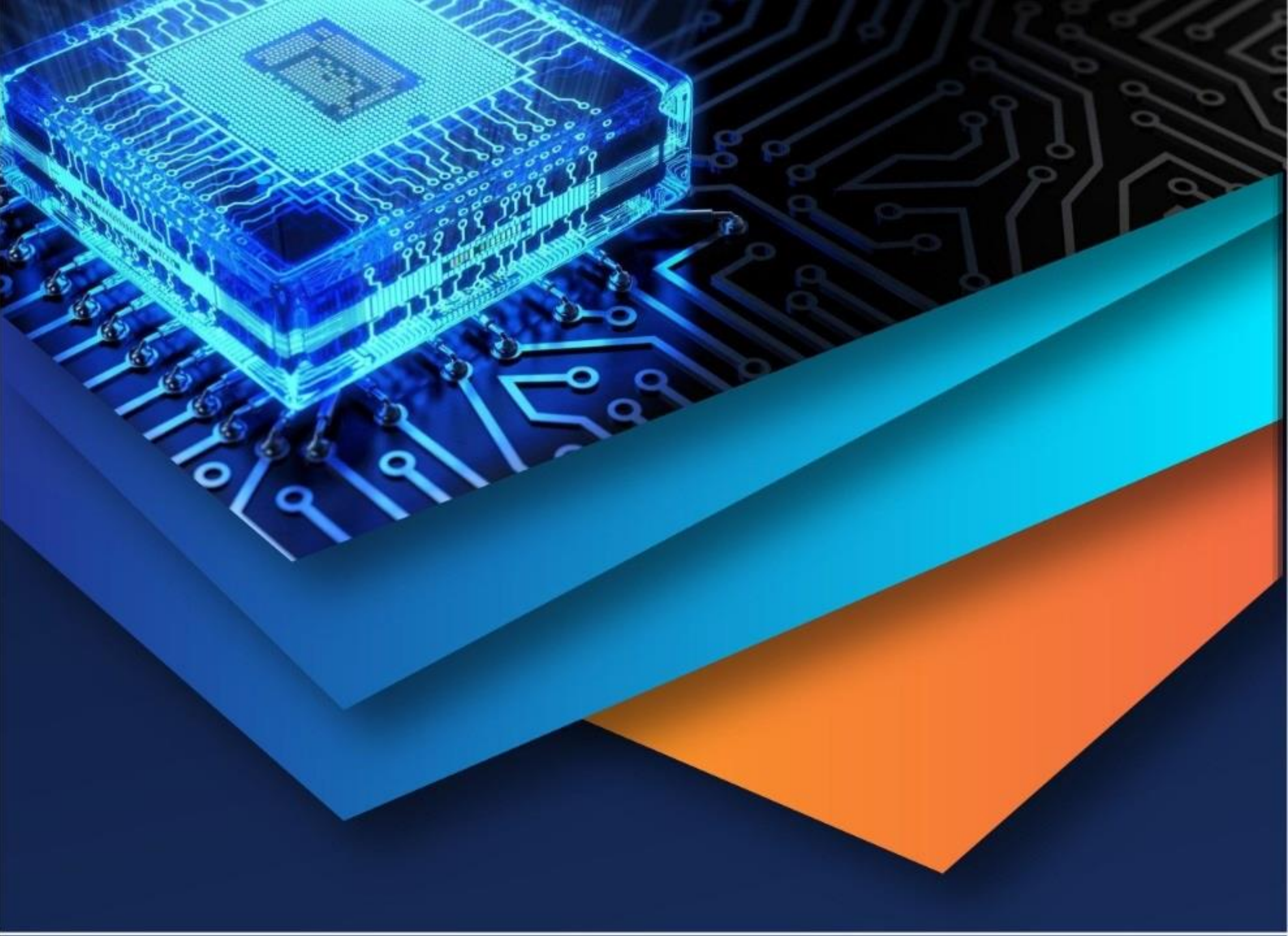

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