



Will International Law Keep Up with the Rise of Hydrogen Energy?

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ABSTRACT

Hydrogen energy has emerged as the global power shift towards clean energy sources in the fight against climate change. However, just as technology moves forward at a fast pace, the legal structures that are required to support the growth of hydrogen are not there, which raises many problems. The hydrogen trade is much more complicated and has many restrictions in the international market; developing nations have challenges like restricted access to hydrogen equipment and infrastructure, demonstrating significant shortcomings in international legal frameworks that guarantee fairness. As for emissions from blue hydrogen and safety issues in storage, these issues demonstrate that global liability frameworks have significant vulnerabilities. The lack of a simple and consistent legal basis for hydrogen production and consumption may impede the development of a hydrogen economy. Some of the important issues that this article discusses are whether the existing international laws can accommodate the growth of hydrogen or whether there is a need to create a new framework as a whole. With the hydrogen revolution already underway, it is time for the laws to catch up to enable a fair, inclusive, and sustainable transition.

Keywords: Hydrogen Energy; International Law; Sustainable Energy Transition; Environmental Justice

1. Introduction

The call for a clean energy transition has shifted the focus of the international community on sustainable development to hydrogen energy[1, 2]. With countries seeking ways how to achieve their respective targets set under the Paris Agreement, green hydrogen is seen to revolutionize the process of decarbonizing heavily emitting sectors, cutting down the use of fossil fuels, and promoting a net-zero economy[3, 4]. However, the reality is that behind the idea of hydrogen, several legal, regulatory, and economic issues require a solution[5-7]. Its cleanness and compatibility with renewable power sources make it a basis for future energy planning. Hydrogen has the possibility of enabling sectors such as steel manufacturing, long-distance transportation, and aviation to be green, which are difficult to electrify; however, change to a hydrogen economy requires more than a technological shift[8]. This implies the need for coherent legal regimes at the international level that would support trade in hydrogen and its derivatives, manage environmental challenges, and promote fair distribution of hydrogen technologies. Another critical question arises as to whether modern international laws are well prepared for this change; the answer, however, is no[9, 10]. There is no specific regulation that targets hydrogen, but the current treaties and agreements mainly discuss renewable energy in a general sense[11, 12]. For instance, even as the Paris Agreement offers a global climate blueprint, it does not contain the specifics of how hydrogen energy will be regulated. Trade laws also have issues in governing and addressing the dispute of the intellectual properties of the transportation of hydrogen across borders. If the international community does not respond to this critical issue then the lack of coherent rules may cause trade conflicts, slow down the technological progress, and expand the gap between the developed and the developing nations[13]. Furthermore, the environmental impacts of hydrogen production like emissions from blue hydrogen and risks in hydrogen storage are still not well handled by the international legal frameworks on liability[14]. If there is no coherent strategy for the hydrogen economy, this can only exacerbate global inequality as opposed to mitigating it.



This article critically observes the intersection of hydrogen energy and international law, raising the following main objectives:

- To determine whether current international legal instruments can be used to enhance hydrogen energy or if there is a need for new conventions like the International Hydrogen Protocol.
- To examine the legal issues affecting hydrogen production, trade, and storage, especially in matters of international relations and environmental issues.
- To understand how international organizations and developing countries can contribute to a fair and sustainable hydrogen energy transition.
- To put forward practical suggestions for closing the gap in legislation that may impede the further development of hydrogen energy.

2. Methodology

In this article, the authors have used a multidisciplinary and analytical approach[15] to examine the complicated connection between hydrogen energy and international law. Primary sources include international treaties, legal instruments, and case laws while secondary sources include peer-reviewed articles, reports from International Energy Agency (IEA) and International Renewable Energy Agency (IRENA), and policy briefs. The combination of these different materials reveals the deficiencies of the current legislation and offers practical suggestions on how to overcome them. The study used a comparative analysis as the main approach to data analysis[16, 17]; comparing and contrasting current strategies in hydrogen governance including the EU's Hydrogen Strategy and the issues affecting the developing world. This makes it possible to identify the effect of inequality in the distribution of technology, funding, and legal framework on the advancement of hydrogen energy across the world.

This article raised thought-provoking questions designed to challenge conventional thinking: Is the legal protection of Intellectual Property impeding the formation of partnerships and collaborations for the advancement of green hydrogen technology? Is it possible to uphold trade laws that will also help address hydrogen energy issues and achieve fairness in access for all countries? These questions not only direct the analysis but also help to keep the article practical, addressing real problems and providing practical, comprehensive, and universal solutions. In this methodology, the article aims to appeal to both academics and policymakers through a combination of theoretical analysis and policy-relevant findings that would make a valuable contribution to the existing literature on hydrogen energy and international law.

3. International Legal Gaps in Hydrogen Energy Developments

3.1 International Treaties

The emergence of hydrogen energy as one of the main players in the transition to clean energy has revealed systemic gaps in regulation at the international level[18, 19]. As nations race to embrace hydrogen's potential to decarbonize industries and meet net-zero goals, a critical question arises: How ready are current international treaties such as the Paris Agreement to deal with the complex nature of hydrogen energy? The Paris Agreement signed as a success in climate diplomacy, outlines the global climate goals but lacks clear policy solutions for such emerging sectors as hydrogen energy[20]. Though it focuses on the promotion of renewable energy sources, it lacks any specific information on the methods of producing hydrogen, hydrogen trading, and safety measures[21]. This absence of definition means that hydrogen energy remains in legal limbo, and countries are free to define its function based on their national concerns. For example, is blue hydrogen, which is produced from fossil fuels with the use of carbon capture, a 'clean energy'? Or does it weaken the Paris Agreement's more general aims of emissions reduction? These questions remain unanswered and, therefore, point to a major void in the existing international governance system. Herein, the lack of a single Hydrogen Protocol presents practical issues that might impede the global adoption of hydrogen[22]. Due to the lack of standardized regulations in the production of hydrogen, the methods used differ greatly and thus have a different



potential to harm the environment[23]. For example, while the European Union is promoting green hydrogen under the principle of sustainability, other parts of the world are still using carbon-based processes. This divergence does not only potentially lead to trade conflicts but also impedes the international recognition of hydrogen as a clean energy carrier; also, the legal uncertainty impacts cross-border hydrogen trade. The transportation of hydrogen whether as pipeline hydrogen or liquefied hydrogen needs safety standards which are still different across countries? The lack of international regulation and standards presents practical challenges and makes large-scale hydrogen projects unattractive for the private sector[24].

Further, the ownership of rights over hydrogen technologies is still a problem as the developed countries are controlling the strategic technologies while the developing countries are still struggling to get the technology that they need for the adoption of hydrogen. Is a Hydrogen Protocol the solution? A specific Hydrogen Protocol could be useful as the link between the countries in terms of energy management[25]. Such a protocol would set global benchmarks for hydrogen production, which would exclude unsustainable methods such as grey hydrogen. It might coordinate the safety standards of storage and transportation, which will minimize the probability of incidents and enhance the confidence of trading parties. In addition, it could address equity through a provision that requires technology transfer and financial support to the developing countries to make hydrogen energy an international remedy to climate change[13]. What are the risks of delay? The danger of a lack of determined action on this front is that the world faces a future of a bifurcated hydrogen economy where only a handful of wealthy countries enjoy its benefits, further entrenching global divisions[26]. Worse still, this may create disparate regulations that would cause accidents that are detrimental to the environment and safety hence damaging the reputation of hydrogen as a clean energy source. The message is clear: Hydrogen Energy has the potential to be the future foundation of clean energy, but it needs International Law to deliver on the potential. The world requires more than large climate conventions and treaties; the world needs specific, enforceable, and practical guidelines that fill the existing gaps in hydrogen energy regulation.

3.2 Regulatory Hurdles and Trade Complexities

The transition to a world where hydrogen is the primary energy source is now at a tipping point, but even though it is a technology that holds a great deal of promise for the future, the road forward is not without challenges such as regulatory issues and trade[18, 27]. These challenges not only pose a risk to the timely expansion of hydrogen options but also bring up essential questions about the preparedness of the international legal system for this new age of energy exchange. The question arises: How can hydrogen be traded across borders when the processes of its transport and trade are not yet fully integrated? Perhaps the most obvious one is the lack of clear guidelines for hydrogen transport that could be applied on the international level. Hydrogen being light, flammable, and difficult to transport needs specific logistics for transportation across geographical locations[28]. However, there are also specific requirements for hydrogen transportation at the country level, including pipeline standards and liquefaction procedures. This is because a standardized regulatory platform is yet to be established, which implies that hydrogen cannot go from one country to another as a commodity. For instance, how can a shift to hydrogen be made if there is no consensus on the storage, transportation, or distribution of Hydrogen between the different regions? This absence of standardization results in slower trading, increased expenses, and lost potential for international collaboration, which is critical for hydrogen to live up to its potential in the energy transition process. Also, the essence of the hydrogen trade is even amplified by the fact that it is environment friendly. What measures can be taken to ensure that hydrogen can meet the growing demand while there are variations in the definition of clean hydrogen across nations? For instance, the European Union has taken to supporting green hydrogen produced from renewable energy, while some countries in the Middle East are more inclined towards blue hydrogen which is produced from fossil fuels but with the added process of carbon capture. This lack of



harmonization leads to trade disputes: should nations consider blue hydrogen as a part of their energy portfolio, or should they wait for the more sustainable green hydrogen? While the public and policymakers may have differing opinions on what constitutes clean energy, how can there be a fair and efficient exportation of hydrogen across countries? At the center of these regulatory issues, is a more complicated, even more contentious, question: Should the possession of IPR impede the access of developing countries to advanced green hydrogen technologies? Companies in developed countries primarily control the technology used in green hydrogen production like the electrolyzers from renewable sources[29]. These technologies are frequently patented, which renders them costly and unaffordable for developing nations. Should these innovations be protected under intellectual property laws when they slow down the global use of hydrogen energy for fighting climate change? Can the world continue to support a system where the ability to decide the future of decarbonization of the world rests in the hands of a few large corporations?

For hydrogen to become a potent tool for decarbonizing industries, weaning off fossil energy sources, and electrifying transportation systems, it is important to see how international laws can address these regulatory and trade barriers[6, 13, 30]. How much longer can we wait for solutions to these problems before the chance of a global hydrogen economy is lost? The time is now, and the answers to these questions will determine the future of hydrogen energy. For the global hydrogen market to fully realize its potential there is a need for international laws to adapt to the changing energy markets. The global push for hydrogen energy as a clean fuel of the future raises an uncomfortable question: Is this shift of transfer fair or does it only pose a threat of worsening the inequality in terms of energy between the developed and the developing countries? As the countries of the Global North is actively developing their hydrogen plans, having strong legal support, significant financing, and innovative solutions, the Global South face significant discrepancies. Furthermore, should the countries that export hydrogen produced from blue hydrogen be made responsible for the emissions from the process? This may cause problems, as there are no specific treaties that address hydrogen's risks and, therefore, there are certain areas of uncertainty. Assessment of legal liability for hydrogen-related accidents could disappear into thin air, especially in areas where national laws are either very weak or have little or no enforcement at all.

4. Critical Legal Questions

Does International Law Require a Bespoke Framework for Hydrogen Energy Governance, or Can Existing Mechanisms Suffice?

Hydrogen energy is both a response to the international environmental agenda and a potential source of economic value, but its legal regulation is dispersed[31, 32]. While the Paris Agreement offers guidelines for cutting carbon-emission levels, it does not contain rules on hydrogen production, its export, or potential dangers. This raises an important question: Can current laws, which developed as a random set for various kinds of energy, successfully address the specifics of hydrogen regulation? The answer is that hydrogen is a solution to renewable energy, a dangerous substance, and a commodity at the same time. Current structures like the UNFCCC offer broad direction but lack the details on such issues as how hydrogen will be transported across borders or who is responsible for hydrogen-related leaks or accidents[33]. It is however possible to create a specific framework that would fit the needs of hydrogen and could build a set of safety standards that would be equal for all, and decrease the number of conflicts in the international trade. The formulation of such a framework requires a weighing of global exigency with domestic concerns, a task yet to be solved.

How Can the Principles of State Sovereignty and Common but Differentiated Responsibilities Be Balanced in Hydrogen Regulation?

Hydrogen energy governance highlights a conflict between two foundational principles of international law: the sovereignty of states and the principle of CBDR[34]. While individual nations have a right to control the production of energy within their territory, hydrogen effects are global and require collective



action[35]. How can the national policies be made to conform to the global climate goals without violating state sovereignty? It is only natural for developed nations with enhanced infrastructure and access to funding to spearhead hydrogen technology advances, but this leaves the issue of equity. Should the Global South be subjected to the same levels of regulation and financial responsibility when they are on the receiving end of climate change impacts despite contributing a mere 10% to the emissions? The principle of CBDR does not support this. Hydrogen governance has to be composed of features that are sensitive to these differences, including technology transfer schemes, funding programs, and diverse regulatory requirements. Without such measures, the hydrogen economy could become part of the problem rather than part of the solution to global inequalities[36].

Can Hydrogen Energy Innovation be shielded from Monopolization under Existing IPR Regimes?

Technological advancements in hydrogen energy and more so green hydrogen technology is one of the most crucial forces transforming the global energy system[37]. However, the current IPR system remains a major hindrance to equal access. So, the critical question is: How to avoid the situation when several large corporations or several countries will dominate in hydrogen development, while the rest of the world will remain in the shadows? Modern IPR systems are commonly protectionist, which means that they issue patents that impede the use of essential technologies by the masses. This is especially so for developing countries which may not have the capital to buy or invest in their hydrogen solutions. The question then becomes: Should international law reform IPR protections to give way to global public goods or not? Some of the potential solutions are compulsory licensing, open-source innovations, and international treaties that allow sharing of the technologies without distorting incentives for innovations. This is why it is not only a legal question of how to protect hydrogen energy innovation from monopolization but also a question of morality. A truly sustainable hydrogen economy cannot thrive if access to its benefits remains concentrated in the hands of a privileged few.

5. Hydrogen Policy and Global Energy Transition

5.1 Key Cases

EU Hydrogen Strategies (2020): A Critical Example of Regulatory Innovation and Trade Tensions

The EU's Hydrogen Strategy launched in 2020 targets to generate between five to ten million tons of renewable hydrogen by 2030 and has identified hydrogen as one of the key enablers of the energy transition in Europe[38-40]. This grand strategy aims to dematerialize numerous segments, such as industry and transportation, and curb greenhouse gas emissions. But does this strategy have the effect of sparking trade tensions? EU's high standards and large subsidies for green hydrogen could harm non-EU exporters, especially developing countries, which cannot afford such investments and do not have the necessary technology. This has made issues of fairness in accessing the growing hydrogen market and the likelihood of trade conflicts to be of major concern; also, this strategy raises questions about compliance with the WTO regulations. The EU's focus on local content requirements and subsidies for domestic hydrogen production may be seen as protectionist practices, which may violate WTO policies that promote free and fair trade. These policies may lead to litigation by non-EU countries challenging the EU's hydrogen plans for compliance with global trade laws.

Neubauer et al. v. Germany (2021): Legal Obligations for Transitioning to Clean Energy

In the Neubauer et al. v. Germany case, the Federal Constitutional Court declared the Climate Protection Act ineffective and the state failed to protect the fundamental rights of young individuals in terms of climate protection after the year 2030[41, 42]. The court ordered the government to set more specific and strict milestones for the protection of future generations[43]. This case raises critical questions: Is current legislation sufficient to prompt the transition to clean energy sources? The ruling shows that the judiciary can and will enforce climate action, and weak or no targets are legally impermissible. It also underlines the need for governments to put in place long-term and coherent climate policies that correspond to constitutional duties towards the rights of people.

5.3 Reports by IEA and IRENA on Hydrogen's Global Potential



Both the IEA and IRENA have conducted comprehensive research on the global capabilities of hydrogen and mentioned that hydrogen would be one of the critical components in the future energy mix. The IEA's Global Hydrogen Review highlights significant growth in hydrogen investments, with the number of projects reaching final investment decisions doubling over the past year, primarily driven by China[44, 45]. This trajectory indicates that low-emission hydrogen production could increase fivefold by 2030. However, there are still issues such as low installed capacity and demand risks due to weak demand signals, and financing, regulatory, and operations barriers. The IEA underlines that policymakers should continue demand creation, decrease costs, as well as define even rules to maintain more investments[46].

According to IRENA, global hydrogen production is currently estimated to be at around 75 MtH₂/yr of pure hydrogen and 45 MtH₂/yr as a component of mixed gases, and it contributes to about 3% of the end-use energy[47, 48]. In the longer term, IRENA expects hydrogen and its derivatives to meet 14% of final energy demand in the year 2050, which will require more than a five-fold increase in global hydrogen production from its current level[44].

While both agencies project substantial growth for hydrogen in the global energy mix, several critical questions arise:

1. Investment and Infrastructure Development: As it is evident from the above results and analysis, that the current installed capacity is still low, what measures can be taken to enhance infrastructure development to suit the projected demand?

Analysis: Efficient infrastructure growth demands policy harmonization, supportive policies from the public and private sectors, and sufficient funds. Both government and industry players need to work together to reduce bureaucratic barriers, offer incentives for adoption, and fund advanced technology improvements.

2. Policy and Regulatory Frameworks: What are the possible measures that policymakers can take to adapt to existing uncertainties and promote the scaling up of hydrogen production and use?

Analysis: There is a need to develop and enforce policies that outline acceptable practices in generating, transporting, and consuming hydrogen. This involves targeting the take-off rates for green hydrogen, applying carbon costs to make low-carbon hydrogen cost-competitive, and establishing safety frameworks to make hydrogen more acceptable to the public.

6. Recommendations Regarding Gaps in Hydrogen Energy Governance

Establishing a Unified Hydrogen Protocol

Hydrogen production and international trade are not currently governed by any set of standardized global regulations. Is the future of hydrogen best served by a patchwork of disjointed national policies or does it require a coherent global system? An International Hydrogen Protocol should be established and anchored under the umbrella of the United Nations. This protocol has to align the definitions of 'clean hydrogen,' which must be consistent across green, blue, and other hydrogen classifications. It should also establish global safety and transportation guidelines to facilitate the efficient export and import of hydrogen and minimize risks. Further, it has to ensure that the protocol encourages sharing technologies and funding mechanisms to help developed and developing countries. If such a strategy does not exist, then the use of hydrogen as an energy source can become scattered and uncoordinated on a global level.

Tackling the IP Barrier

Current frameworks of intellectual property rights provide significant protection to green hydrogen innovation, which is not easily accessible to the countries in the development phase. Is the world ready to leave the fate of the hydrogen transition in the hands of intellectual property monopolies? International law should also provide provisions for compulsory licensing and public-private partnerships to make green hydrogen technologies affordable to developing nations. Similarly, models such as open source for non-critical innovations should be promoted to enhance collaboration. Thus,



the breakdown of these barriers will make hydrogen development more equitable and inclusive across the globe which will be beneficial for the advancement of technology and sustainability.

Improving the International Liability Regime

Accidents involving hydrogen are potentially dangerous to the environment and human beings. Is current regulation sufficient to address these issues? National and international laws, for example, a new Liability Convention for Hydrogen Energy, should outline the responsibilities of parties in case of cross-border hydrogen energy-related accidents and liabilities. Moreover, they should set rules for the safety audit as well as insurance for hydrogen storage and transportation schemes. Thus, the environmental and financial costs associated with liability risks can deter hydrogen's potential as a clean energy source.

Prioritizing Equitable Access for Developing Nations

The industrialized countries, through entities such as the Green Climate Fund, have to provide long-term financing for investments and human resource development in the Global South. They should also adopt variable regulatory measures that are in proportion to economic and technological development. The latter directly contributes to the achievement of the goal to make hydrogen energy available for all countries and bring the hydrogen revolution to everyone.

Accelerating Technological Development

In its current state, hydrogen is expensive and difficult to scale up as a usable energy source. What inventions are needed to overcome these barriers? The governmental and private sectors need to focus on the development of efficient and low-cost electrolyzers and renewable energy sources, good storage, and transportation methods like ammonia-based carriers and hydrogen pipelines. Through speeding up technological development and decreasing the costs of hydrogen energy, the world can move from the stage of exploring a new type of energy to a stage of having a new main type of energy.

7. Conclusion

Hydrogen energy can be viewed as a symbol of the technological advancement and energy revolution that is yet to come, but it also raises questions of the legal nature and equitable transition path. This article has analyzed the legal, economic, and environmental aspects of hydrogen energy governance and brought out the issues of fragmented regulation and trade, calling for international cooperation. Challenges to the hydrogen economy's development include emissions of blue hydrogen and safety issues related to storage, raising questions about liability regimes and international environmental law. The establishment of a Hydrogen Protocol, including changes to Intellectual Property Rights or IPRs, and proper funding frameworks is critical to making hydrogen energy safe, secure, and available in every country. The potential of hydrogen energy to become a global force for climate justice and economic inclusion can only be achieved through international collaboration. It is impossible to wait any longer – this is the time of hydrogen energy and the laws that will govern it.

References

1. Capurso, T., et al., *Perspective of the role of hydrogen in the 21st century energy transition*. Energy Conversion and Management, 2022. **251**: p. 114898.
2. Kovač, A., M. Paranos, and D. Marcuš, *Hydrogen in energy transition: A review*. International Journal of Hydrogen Energy, 2021. **46**(16): p. 10016-10035.
3. Sadik-Zada, E.R., *Political economy of green hydrogen rollout: A global perspective*. Sustainability, 2021. **13**(23): p. 13464.
4. Wappler, M., et al., *Building the green hydrogen market—Current state and outlook on green hydrogen demand and electrolyzer manufacturing*. International Journal of Hydrogen Energy, 2022. **47**(79): p. 33551-33570.
5. Ball, M. and M. Weeda, *The hydrogen economy—vision or reality?* International Journal of Hydrogen Energy, 2015. **40**(25): p. 7903-7919.
6. Bade, S.O., et al., *Economic, social, and regulatory challenges of green hydrogen production and utilization in the US: A review*. International Journal of Hydrogen Energy, 2024. **49**: p. 314-335.
7. Ahmad, I., J. Afzal, and S. Ahmad, *Legal Framework of Green Hydrogen Production and Hydrogen Economy for Sustainable Development*.



8. Boretta, A. and B.G. Pollet, *Hydrogen economy: Paving the path to a sustainable, low-carbon future*. 2024, Elsevier. p. 307-319.
9. Ballo, A., et al., *Law and policy review on green hydrogen potential in ECOWAS countries*. *Energies*, 2022. **15**(7): p. 2304.
10. Ahmad, I., Afzal, J., & Ahmad, S., *Regulatory Analysis of Energy Law and Hydrogen Economy*, in *Legal Framework of Green Hydrogen Production and Hydrogen Economy for Sustainable Development*. 2025. p. 89-111.
11. Dolci, F., et al., *Incentives and legal barriers for power-to-hydrogen pathways: An international snapshot*. *International Journal of Hydrogen Energy*, 2019. **44**(23): p. 11394-11401.
12. Ahmad, I., Afzal, J., & Ahmad, S., *International Conventions and Regional Treaties Shaping the Hydrogen Economy*, in *Legal Framework of Green Hydrogen Production and Hydrogen Economy for Sustainable Development*. 2025. p. 128-154.
13. Bade, S.O. and O.S. Tomomewo, *A review of governance strategies, policy measures, and regulatory framework for hydrogen energy in the United States*. *International Journal of Hydrogen Energy*, 2024. **78**: p. 1363-1381.
14. Andreasson, L.M. and M. Roggenkamp, *Deliverable 2.2, 2.3-Regulatory Framework: Legal Challenges and Incentives for Developing Hydrogen Offshore*. 2020.
15. Bridson, J.H., et al., *Leaching and extraction of additives from plastic pollution to inform environmental risk: a multidisciplinary review of analytical approaches*. *Journal of Hazardous Materials*, 2021. **414**: p. 125571.
16. Legrand, P., *Comparative legal studies and commitment to theory*. 1995, JSTOR.
17. De Cruz, P., *Comparative law in a changing world*. 2024: Taylor & Francis.
18. Hassan, Q., et al., *Hydrogen role in energy transition: A comparative review*. *Process Safety and Environmental Protection*, 2024.
19. Cheekatamarla, P., *Hydrogen and the Global Energy Transition—Path to Sustainability and Adoption across All Economic Sectors*. *Energies*, 2024. **17**(4): p. 807.
20. Hosseini, S.E., *Hydrogen Diplomacy*. 2024: Future Publishing LLC.
21. Kuramochi, T., et al., *Supporting the Paris Agreement through international cooperation: potential contributions, institutional robustness, and progress of Glasgow climate initiatives*. *npj Climate Action*, 2024. **3**(1): p. 31.
22. Islam, A., et al., *Accelerating the green hydrogen revolution: A comprehensive analysis of technological advancements and policy interventions*. *International Journal of Hydrogen Energy*, 2024. **67**: p. 458-486.
23. Hassan, Q., et al., *Hydrogen as an energy carrier: properties, storage methods, challenges, and future implications*. *Environment Systems and Decisions*, 2024. **44**(2): p. 327-350.
24. White, L.V., D. Gourlay, and E. Aisbett, *Potential market failures inhibiting the development of a green hydrogen export industry*, in *Towards Hydrogen Infrastructure*. 2024, Elsevier. p. 39-58.
25. Hassan, Q., et al., *Green hydrogen: A pathway to a sustainable energy future*. *International Journal of Hydrogen Energy*, 2024. **50**: p. 310-333.
26. Ahmad, I., Afzal, J., & Ahmad, S., *Legal Framework for Hydrogen Economy and Future Directions of Global Green Hydrogen Economy*, in *Legal Framework of Green Hydrogen Production and Hydrogen Economy for Sustainable Development*. 2025. p. 155-185.
27. Blay-Roger, R., et al., *Natural hydrogen in the energy transition: Fundamentals, promise, and enigmas*. *Renewable and Sustainable Energy Reviews*, 2024. **189**: p. 113888.
28. Patel, S.K.S., et al., *Recent developments in hydrogen production, storage, and transportation: Challenges, opportunities, and perspectives*. *Fire*, 2024. **7**(7): p. 233.
29. Nnabuife, S.G., et al., *Integration of renewable energy sources in tandem with electrolysis: A technology review for green hydrogen production*. *International Journal of Hydrogen Energy*, 2024.
30. Ashari, P.A. and K. Blind, *The effects of hydrogen research and innovation on international hydrogen trade*. *Energy Policy*, 2024. **186**: p. 113974.
31. Fleming, R., *The Cambridge Handbook of Hydrogen and the Law*. 2024: Cambridge University Press.
32. Flath, L., J. Kemmerzell, and M. Knodt, *Hydrogen governance in Germany: a challenge for federal coordination*. *Regional & Federal Studies*, 2024. **34**(5): p. 757-779.
33. Rigas, F., *Hydrogen Safety: Production, Transport, Storage, Use, and the Environment*. 2024: CRC Press.
34. Olawuyi, D.S., et al., *Net Zero and Natural Resources Law: Sovereignty, Security, and Solidarity in the Clean Energy Transition*. 2024: Oxford University Press.
35. Pereira, E.G., T.L. Muinzer, and P.R. Baker, *Energy Law and the Sustainable Development Goals: Host Government Instruments for Sustainability in Oil and Gas Operations*. 2024: Taylor & Francis.
36. Rifkin, J., *The hydrogen economy*. 2003: Penguin.



37. Winter, C.-J., *Hydrogen energy—Abundant, efficient, clean: A debate over the energy-system-of-change*. International journal of hydrogen energy, 2009. **34**(14): p. S1-S52.
38. Genovese, M., et al., *Power-to-hydrogen and hydrogen-to-X energy systems for the industry of the future in Europe*. International Journal of Hydrogen Energy, 2023. **48**(44): p. 16545-16568.
39. Undertaking, H.J., *Hydrogen roadmap Europe: a sustainable pathway for the European energy transition*. 2019.
40. Lagioia, G., M.P. Spinelli, and V. Amicarelli, *Blue and green hydrogen energy to meet European Union decarbonisation objectives. An overview of perspectives and the current state of affairs*. International Journal of Hydrogen Energy, 2023. **48**(4): p. 1304-1322.
41. Gentile, C., *Climate Change and the Extraterritorial Reach of the State Duty to Protect*, in *Yearbook of Sustainable Smart Mining and Energy 2022: Technical, Economic and Legal Framework*. 2023, Springer. p. 125-142.
42. Ahmad, I., Afzal, J., & Ahmad, S, *Critical Analysis of Hydrogen Energy Development: Germany's Approach to Balancing Economic Rights and Environmental Sustainability*, in *Legal Framework of Green Hydrogen Production and Hydrogen Economy for Sustainable Development*. 2025. p. 112-127.
43. Kotzé, L.J., *Neubauer et al. versus Germany: Planetary Climate Litigation for the Anthropocene?* German Law Journal, 2021. **22**(8): p. 1423-1444.
44. Marzouk, O.A., *Expectations for the role of hydrogen and its derivatives in different sectors through analysis of the four energy scenarios: IEA-STEPS, IEA-NZE, IRENA-PES, and IRENA-1.5 C*. Energies, 2024. **17**(3): p. 646.
45. Ségur-Eltz, P., *Strategic geoeconomics of hydrogen: shaping Europe's future energy market*. 2024, Technische Universität Wien.
46. Avila, N., et al., *The energy challenge in sub-Saharan Africa: A guide for advocates and policy makers*. Generating Energy for Sustainable and Equitable Development, Part, 2017. **1**: p. 1-79.
47. Khaleel, M., et al., *Towards hydrogen sector investments for achieving sustainable electricity generation*. Journal of Solar Energy and Sustainable Development, 2024. **13**(1): p. 71-96.
48. Monforti Ferrario, A., et al., *Role of Hydrogen in Low-Carbon Energy Future*. Technologies for Integrated Energy Systems and Networks, 2022: p. 71-104.

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