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How can Japan help create a sustainable hydrogen society in Asia?

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ADB Working Paper Series

HOW CAN JAPAN HELP CREATE A SUSTAINABLE HYDROGEN SOCIETY IN ASIA?

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Abstract

Japan has adopted several policies that signal its intent to rely on hydrogen to achieve net-zero climate goals. However, many of those same policies are unclear about its support for a transition to green hydrogen. Relying on gray and blue hydrogen without a transition to green hydrogen will harm the climate. It will also result in several other lost international cooperation and local socioeconomic benefits. This paper argues that greater clarity about the transition to green hydrogen will help strengthen the alignment with Japan's international climate strategy and local revitalization policies. It then proposes a set of recommendations that can clarify its support for transitioning to green hydrogen in national policies as well as international climate and local revitalization strategies.

Keywords: hydrogen, co-innovation, net zero, green hydrogen, Japan, Asia

JEL Classification: Q42, Q48, Q49

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1. INTRODUCTION

Many countries in Asia have demonstrated an interest in relying on hydrogen to achieve net-zero goals. This interest is warranted since Asia's concentration of heavy industries and fast-rising transport emissions require alternative fuels. Japan has been at the forefront of these efforts. However, whether Japan's hydrogen strategy contributes to ambitious climate goals remains an open question. The reason that question remains open is that Japan's policies are unclear about intentions to transition from blue and gray to green hydrogen.

This paper argues that greater clarity about the transition to green hydrogen will help Japan achieve international cooperation and local socioeconomic benefits. It then outlines recommendations that can clarify its support for transitioning to green hydrogen. Those recommendations include more precise language and tangible milestones for transitions in national policies. They also entail making clearer statements about the intent to support green hydrogen and related actions in international climate and local revitalization strategies that make that commitment credible.

This above argument is not only important for policymakers but for several lines of research on hydrogen. One branch of relevant research underlines that hydrogen is not universally good for the environment. For instance, studies have used analysis to demonstrate that hydrogen strategies need to avoid negative impacts on local ecosystems and freshwater availability (Panchenko et al. 2023). Others have noted that while hydrogen in the energy mix could replace fossil fuels, gaps exist regarding the supply chain and hydrogen production in, for instance, the shipping industry and hydrogen fuel cell vehicles (Atilhan et al. 2021; Khan et al. 2021). Though informative, much of this work has a stronger technical than policy focus.

A second line of work is more strongly linked to policy. This includes earlier studies that advocated that Japan introduce long-term plans for increasing the share of hydrogen in its energy mix (Ohta and Abe 1985). A similar, more recent argument can be found in work on opportunities for collaborating with countries in Asia to overcome some of the aforementioned technical hurdles (Aditiya and Aziz 2021). While these studies shed important light on policy, they do not underline the multiple local and international cooperation benefits from committing to transition pathways supporting green hydrogen in Japan (and other countries in Asia).

There is thus a significant gap in the literature. This paper fills this gap by not only examining Japan's hydrogen policies but also highlighting the benefits of transitioning to green hydrogen. It further examines the role of technology co-innovation in supporting mutually beneficial collaboration on green hydrogen between Japan and other countries in Asia.

The paper is divided into seven sections. The following section gives a brief overview of the potential of hydrogen and the obstacles to achieving it, and the third section looks at Japan's national hydrogen strategies, while the fourth outlines the advantages of switching to green hydrogen. The fifth section examines Japan's role in leading hydrogen economy in Asia. The sixth section offers policy recommendations and emphasizes how regional cooperation could support those recommendations. The final section concludes with a suggestion for further research.

2. HYDROGEN'S POTENTIAL IN, AND BARRIERS TO, TRANSITIONING TO A NET-ZERO ECONOMY

Hydrogen has the potential to play a vital role in the transition to a net-zero economy, as it can be used as a clean energy carrier to store and transport energy from renewable sources such as solar and wind. It can also be used to decarbonize a variety of sectors, including transportation, industry, and heating, that are difficult to electrify using electricity alone. However, there are also significant barriers to the widespread adoption of hydrogen in the transition to net zero. These hurdles include: the high cost of producing “green” hydrogen using electrolysis and renewable energy; the lack of infrastructure for the production, storage, and distribution of hydrogen; and limited public awareness and understanding of hydrogen as a clean energy source. Despite these challenges, the potential benefits of hydrogen make it a potentially important driver in the transition to a net-zero economy.

Hydrogen's Potential to Transition to Net Zero

The transition to hydrogen can help reduce emissions and achieve net-zero goals (IPCC 2018), particularly in sectors that are difficult to electrify. These sectors include industries such as steelmaking, high-temperature heating, and long-distance transport. In these areas, hydrogen can be used as a cleaner alternative to fossil fuels, reducing emissions from production processes.

Hydrogen can also play a complementary role in the transition to renewable energy. The intermittent nature of renewable energy sources, such as wind and solar, can be a challenge to grid stability. Hydrogen can provide load balancing to smooth out fluctuations in demand and supply. Electrolysis, the process of splitting water molecules into hydrogen and oxygen, can be used to store excess electricity generated by renewable energy sources. When there is little wind or sun, stored hydrogen can then be burned in gas turbines to generate electricity.

Power-to-gas (P2G) is another way that hydrogen can be used as a form of renewable energy storage. This surplus electricity can be used for green hydrogen production and then consumed when needed (Thorpe 2016). This hydrogen can then be deployed to generate electricity or as a fuel for transport and industrial purposes. Importantly, the use of hydrogen as energy storage does not incur any energy loss over long periods, thus reducing emissions.

Hydrogen is potentially a key contributor to net-zero emission pathways globally (IEA 2019; Hydrogen Council 2021), but its impacts are arguably most promising in Asia. The region is home to many rapidly developing economies that will require alternative fuels in many of the sectors mentioned previously. It is therefore not surprising that governments and private companies in Asia are investing (Hydrogen Council 2021a; BBC 2021; Government of UK 2021) in hydrogen domestically and supply chains regionally.

Barriers to the Development of Hydrogen

While there is considerable potential for hydrogen in Asia, its widespread deployment is far from a foregone conclusion. One of the chief barriers to its spread is the issue of economics. The cost of hydrogen needs to be reduced across the hydrogen supply chain, i.e., production, transport, storage, and usage (IEA 2019). To contribute to decarbonization, hydrogen should be produced using green technologies. However, these methods add costs and uncertainty to the use of hydrogen as an energy source.

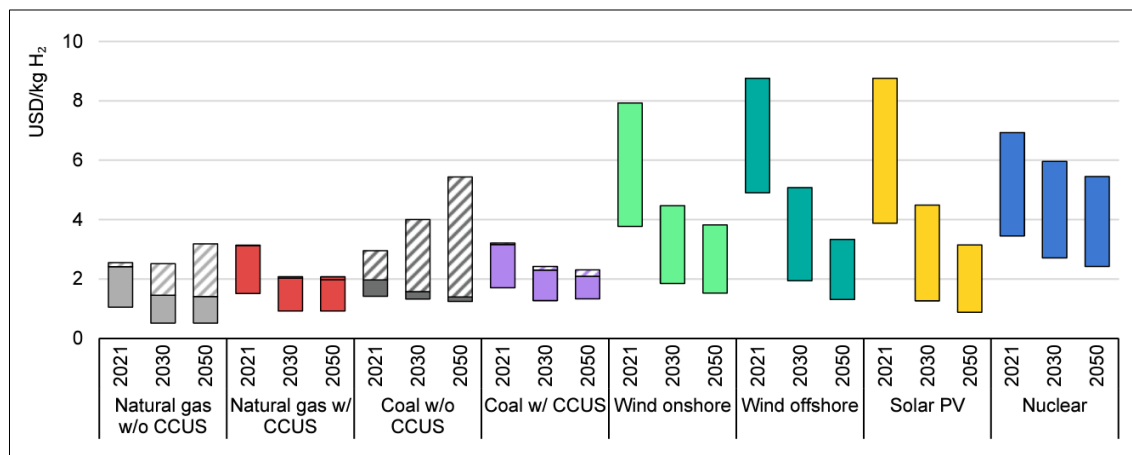
To achieve a hydrogen-based energy system, significant investments in hydrogen production and infrastructure are required. Also, it is crucial to recognize that hydrogen can be produced from a variety of sources that would not reduce emissions, including fossil fuels and biomass. To achieve net-zero emissions, hydrogen has to be produced from clean sources like water and wind energy. There are also issues related to hydrogen transportation and storage—such as the lack of a comprehensive hydrogen infrastructure, the high cost of developing and maintaining hydrogen storage systems, and the lack of suitable materials for storing hydrogen in large quantities—though research and development are identifying ways to make hydrogen increasingly cost-effective and easier to implement in large-scale systems.

Another challenge—and the one most central to this paper—involves the impacts of hydrogen on climate change. Green hydrogen that is produced from renewables using electrolysis can help mitigate climate change. On the other hand, producing hydrogen from coal, oil, or gas is a carbon-intensive process and does not deliver climate benefits. Meanwhile, according to life cycle assessments, “blue” hydrogen produced from methane reformulation with carbon capture and storage (CCS) and blue ammonia produced from lignite reformulation with CCS are not considered environmentally friendly (Howarth and Jacobson 2021). If there are no clearly defined transition pathways, investing in only “gray” and “blue” hydrogen could stall a shift to cleaner forms of energy.

In addition, some of the cost and sustainability barriers overlap. Figure 1 shows that the process of generating green hydrogen is expensive compared to the alternatives. The production cost of green hydrogen is estimated to be between USD2.5/kgH₂ and USD6/kgH₂ in the short run (KPMG 2020). Improving the cost-efficiency of green hydrogen-producing technologies is a prerequisite for green hydrogen rollout (Otsuki et al. 2019). The good news is that some studies show progress on this front, with the lower range of green hydrogen becoming increasingly cost-competitive with blue hydrogen. As technologies improve and renewable power generation gets cheaper, green hydrogen is expected to become more affordable (IRENA 2022).

Even when cost parity is achieved, the expansion of green hydrogen may still not be a preferred policy choice. For many countries, the priority may be satisfying the electricity demand from renewable resources. In Japan, for instance, the green hydrogen production cost is estimated to come down to USD2.4/kgH₂ in 2050, but Japan is expected to use its renewable potential for power generation (IRENA 2022), and import hydrogen from outside the country. Developing a hydrogen economy thus necessitates the development of a hydrogen market and supply chain.

Figure 1: Levelized Cost of Hydrogen Production by Technology in 2021 for Net-Zero Emissions by 2050 Scenario, 2030 and 2050



Source: (IEA 2022).

Another barrier is related to the current regulations and policies. While many countries have set ambitious targets for the deployment of green hydrogen, policies and regulations are still not fully supportive of its development. The lack of clear and consistent regulations and policies can make it difficult for companies to invest in green hydrogen projects. Additionally, in some cases, regulations and policies may not be conducive to the development of green hydrogen, making it less attractive for private investment. Similarly, a lack of public awareness and understanding of green hydrogen can also act as a barrier to its development. There is a need to educate and inform the public about the benefits of green hydrogen and its potential to play a crucial role in the transition to a low-carbon energy system. Additionally, addressing any misconceptions or concerns about green hydrogen can help to build support for its adoption.

Overall, while there are challenges to be overcome, hydrogen has the potential to play a significant role in achieving global net-zero emission goals. Its use in various sectors, and its ability to store and transport energy, make it an essential piece of the net-zero puzzle. With ongoing investment and research, the potential for hydrogen to contribute to a low-carbon future is becoming increasingly clear.

3. JAPAN'S HYDROGEN POLICIES AND STRATEGIES

This section explores how Japan's hydrogen strategy has managed the above barriers but also remained unclear on how it will transition to green hydrogen. While the focus is on Japan, it is worth pointing out that other countries in Asia are also promoting hydrogen. This may open opportunities for learning across countries (see Box 1).

Box 1: Hydrogen Strategies in Asia

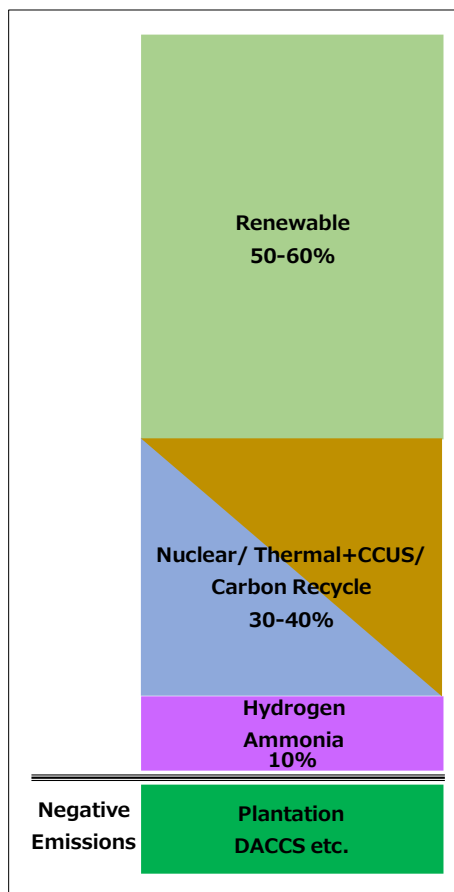
To date, a few countries in the Asia and the Pacific region have developed national hydrogen strategies or roadmaps: These include the Republic of Korea in 2019 and India in 2021, and in 2021, the People's Republic of China (PRC) promulgated hydrogen strategies.

- The Republic of Korea's Hydrogen Strategy highlights several achievements. The country has gained a reputation for mass-producing hydrogen fuel cell electric vehicles since 2013 and has also had success with fuel cells development. In 2018, the release of commercial cars with the longest driving range was seen as a symbol of the Republic of Korea's success in this field.
- In 2021, India announced the National Hydrogen Mission, a strategy aimed at making the country a global leader in green hydrogen production and use. The mission is currently being developed and will have both short-term (4–10 years) and long-term goals. Its objectives include prioritizing and developing green hydrogen, using hydrogen as a storage option for renewable energy, meeting the energy needs of the industry with hydrogen supplies, reducing reliance on fossil fuels, and providing fuel for the transportation sector. The mission also aims to turn India into a global manufacturing hub for hydrogen and fuel cell technologies (MNRE 2021). The mission was approved by the Indian Cabinet in January 2023. The likely outcomes of the mission by 2030 include: the development of a green hydrogen production capacity of at least 5 MMT (million metric tonnes) per annum with an associated renewable energy capacity addition of about 125 GW in the country; over eight lakh crore (\$105.9 billion) in total investments; the creation of over 600,000 jobs; a cumulative reduction in fossil fuel imports over one lakh crore INR (\$13.7 billion); the abatement of nearly 50 MMT of annual greenhouse gas emissions (PIB 2023).
- In June 2021, the China Hydrogen Alliance released a white paper titled "Hydrogen Energy and Fuel Cell Industry in China 2020," which estimates that the demand for hydrogen in the PRC will increase from 33.42 to 130 Mt by 2060. This increase in demand could assist the PRC in achieving its carbon neutrality goals. While the PRC has made significant progress in the development of renewable and clean technologies, it has not yet matched the progress made by Japan or the Republic of Korea in the hydrogen sector.

The Hydrogen Basic Strategy also aims to establish international supply chains for hydrogen production, storage, transportation, and use to support the production of hydrogen abroad. As part of this strategy, several demonstration projects for the production and importation of carbon-free hydrogen have been launched.

Since the development of the 2017 Hydrogen Basic Strategy, shifts in Japan's broader climate policy have triggered a marked increase in interest in hydrogen. This interest began to rise in October 2020 when former Prime Minister Suga Yoshihide announced that Japan would achieve carbon neutrality by 2050. Since that announcement, renewable energy (RE) and hydrogen, as well as ammonia, have begun to feature more centrally in Japan's energy plans. The growing role of these sources is illustrated in Japan's Strategic Energy Plan, which projects that renewables would comprise 50%–60%, while hydrogen and ammonia would make up 10% by 2050 (Figure 2).

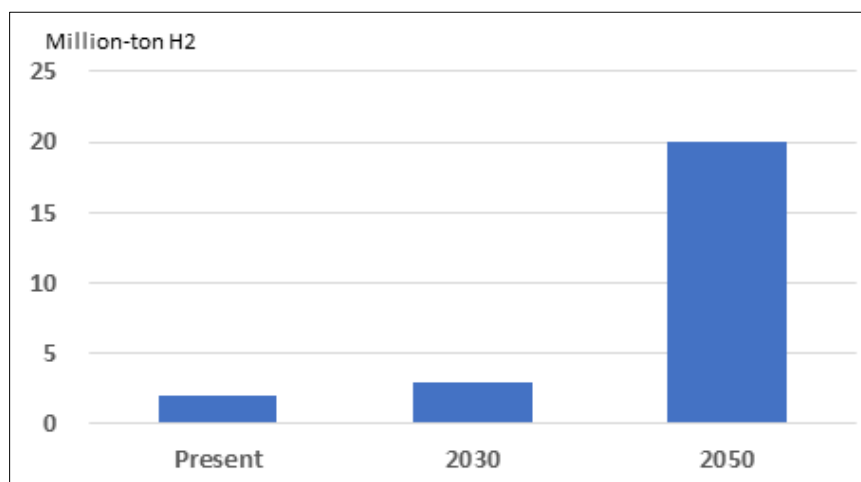
Figure 2: Japanese Government's Assumption of Power Generation Mix to Achieve Carbon Neutrality by 2050



Source: By author, based on information in Green Growth Strategy Through Achieving Carbon Neutrality in 2050 (Ministry of Economy, Trade and Industry 2021, p. 5)

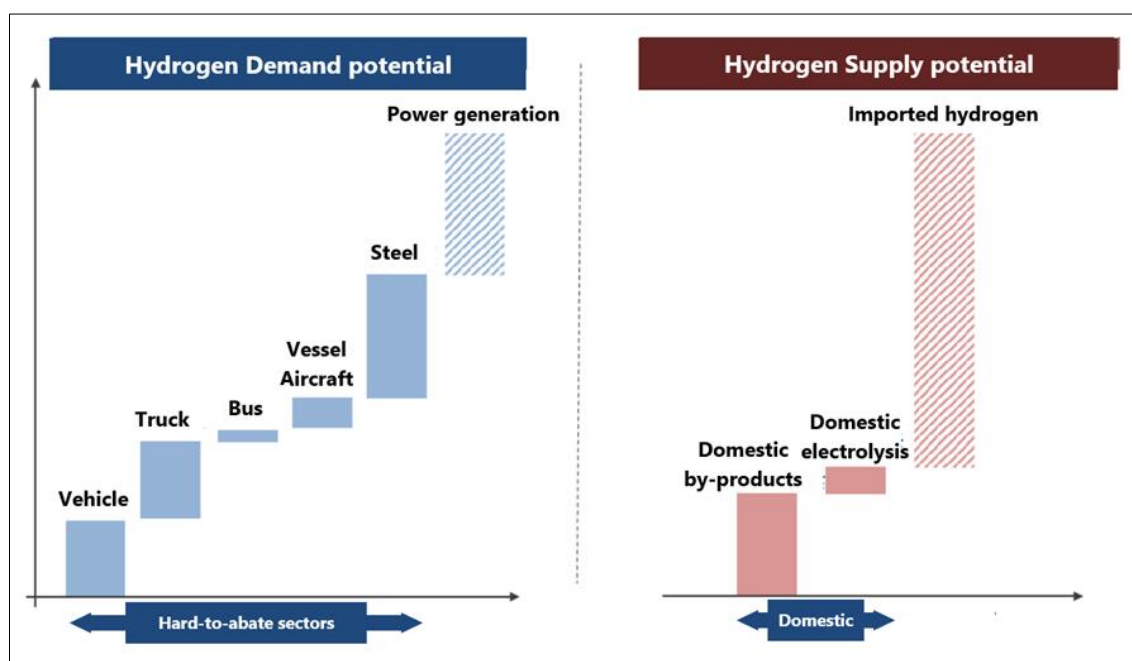
It further merits emphasizing that the estimates in the above graph could be adjusted based on other sources of energy. For instance, the future of nuclear/thermal+CCUS/carbon recycling has remained uncertain since the Fukushima nuclear accident in 2011. Moreover, the status of CCUS is uncertain, with a test plant in Hokkaido able to store only 0.3 million tons of CO₂ whereas Japan's CO₂ emission from the power sector was 450 million tons of CO₂ in 2018. Carbon recycling and power generation using hydrogen and ammonia are still under development, suggesting more uncertainty.

Other strategies have suggested the importance of hydrogen—even given this uncertainty. According to Japan's Clean Energy Strategy, the government estimates that the annual domestic hydrogen demand will be 3 million tons in 2030 and reach 20 million tonnes in 2050. Currently, 2 million tonnes of hydrogen are produced as by-products from oil refinery plants. The strategy, therefore, aims to multiply the current amount of hydrogen tenfold by 2050 (see Figure 3).

Figure 3: Japan's Estimated Domestic Hydrogen Demand

Source: Clean Energy Strategy Interim Review (Ministry of Economy, Trade and Industry 2022, p. 62).

It is also clear from Japan's Clean Energy Strategy that *domestic* hydrogen production will not be at the levels needed to meet demands in 2050 (Figure 4). This is partly because the production of hydrogen as a by-product at oil refineries is limited. It is further compounded by the fact that green hydrogen produced from water electrolysis is also insufficient due to the shortage of renewable energy and the high cost of electrolyzers. This shortfall once again underscores the need for Japan to import hydrogen from other countries. Fortunately, some work in this area is already underway. A major hydrogen-related agenda for Japan is to develop a robust hydrogen supply chain (Nakano 2021), with a plan to invest up to 300 billion Japanese yen toward that end (Reuters 2021).

Figure 4: Prospective Hydrogen Demand and Supply Image in 2050

Source: Discussion toward the realization of 2050 carbon neutral (Ministry of Trade, Industry and Energy 2020).

Though Japan's relevant policies and strategies increasingly suggest the importance of hydrogen, the support for gray, blue, and green hydrogen is still unclear. For instance, METI's Ideal Energy Policy towards 2030 states: "[I]t is an important approach to expand the hydrogen market by spreading gray hydrogen for the time being, then introduce blue and green hydrogen with technology development and cost reduction" (Ministry of Economy, Trade and Industry 2021). The report does not state when Japan will switch from gray to blue and green hydrogen or how to procure hydrogen overseas. In other instances, METI appears to back hydrogen and ammonia co-firing by quoting IAEA World Energy Outlook 2019 data showing that in 2040 Asia and the Pacific will still depend on coal in the power sector comprising 40% of 1,820 GW (Ministry of Economy, Trade and Industry 2022).

Other more general signs of uncertainty include a lack of clarity on how Japan sees the phasing out of coal. On this point, several other countries (CoP UK2021 2021) have committed to the Global Coal to Clean Power Transition Statement at COP 26 in 2021 and to ending coal within the 2040s. Instead, Japan has supported the policy to co-fire coal with ammonia and hydrogen with natural gas for power generation as well as using hydrogen in hard-to-abate industrial sectors.

4. THE BENEFITS OF TRANSITIONING TO GREEN HYDROGEN

This section argues that there are significant benefits to be gained from greater clarity about the transition to green hydrogen. Some of these benefits involve stronger alignment with Japan's international decarbonization strategy, while others involve enhanced coherence with local revitalization strategies.

Strengthening Energy Security

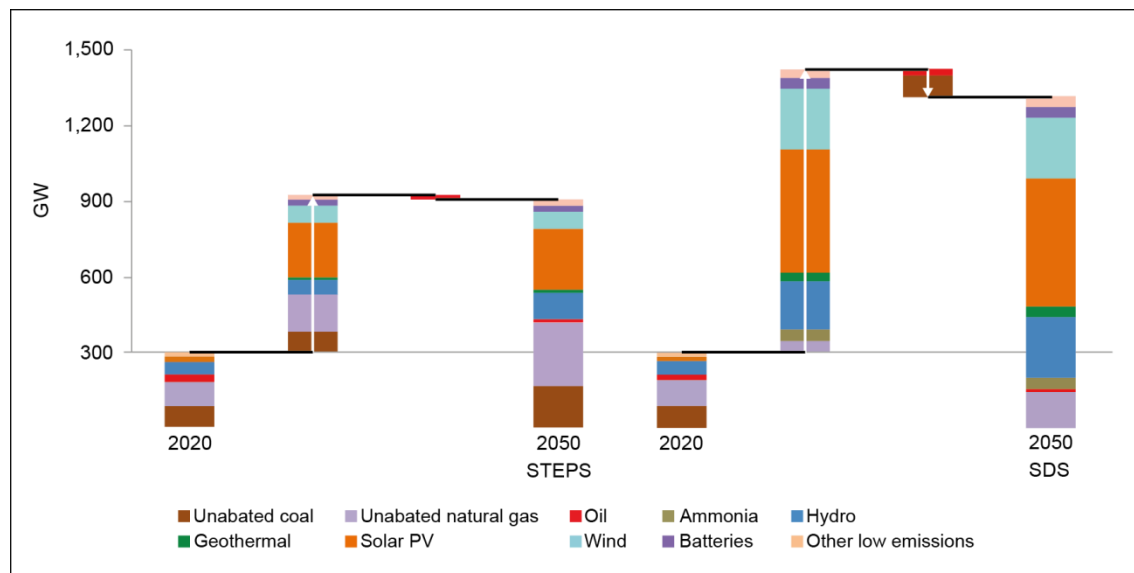
Japan is heavily reliant on imported fossil fuels, such as oil and natural gas, to meet its energy needs. This reliance makes it vulnerable to price fluctuations and supply disruptions, which can have negative impacts on the economy and the welfare of its citizens. By producing its green hydrogen using renewable energy sources, such as solar and wind, Japan can reduce its reliance on imported fossil fuels and increase its energy security. A study by Otsuki and colleagues (Otsuki et al. 2019) found that green hydrogen production using renewable energy sources could provide a stable and reliable source of energy for Japan, particularly in areas with high levels of renewable energy generation. The authors also noted that green hydrogen production could be integrated into Japan's existing energy infrastructure, including the power grid and natural gas network, which could help to increase the flexibility and resilience of the energy system.

Alignment with Japan's International Climate Strategy

At COP 26, Prime Minister Kishida pledged up to \$10 billion in funds over five years to support Asia's decarbonization (see Figure 5 for an illustration of how technology assistance is being allocated to help achieve net-zero goals in Asia's power sector). For geopolitical reasons, a significant proportion of this assistance will likely flow to Southeast Asia. Though Southeast Asia relied on renewables for nearly a quarter of its total generation—mostly from hydropower—there is considerable potential to introduce other forms of renewables that would support green hydrogen (International Energy

Agency 2022). Figure 5 compares the electricity capacity between the stated policies scenario (left) and the sustainable development scenario (right). In the STEPS, the share of renewables increases until it reaches nearly 40% by 2050. In the SDS (Figure 5), renewables would increase to 85%. To achieve a level of 85% by 2050, countries need to add 1,100 GW of renewable capacity in the next 30 years—equivalent to the total renewable capacity of the PRC and India combined (International Energy Agency, 2022).

Figure 5: Change in Electricity Capacity in the Stated Policies Scenario and Sustainable Development Scenario, 2020 to 2050

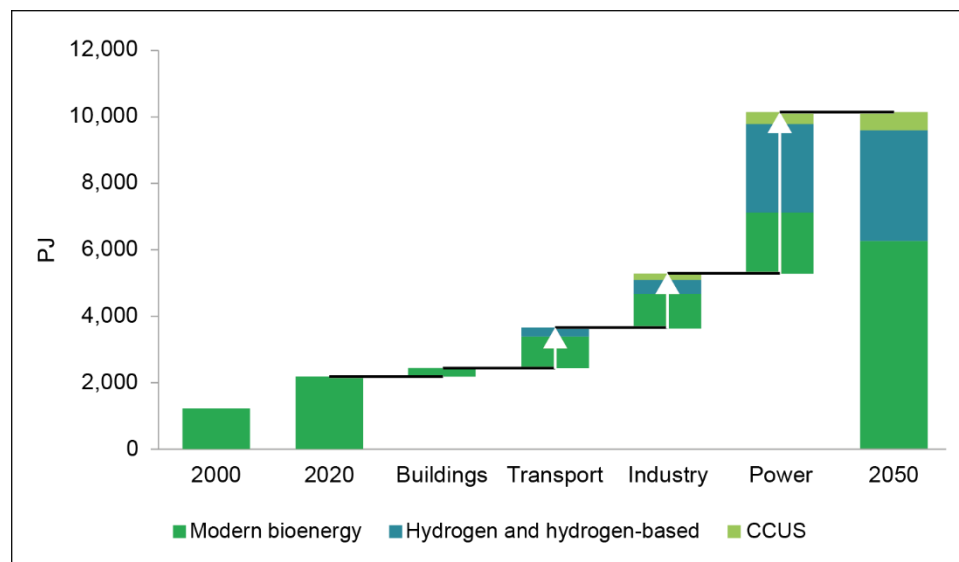


Note: "Other low emissions" includes nuclear, CCUS, and other forms of renewables.

Source: Southeast Asian Energy Outlook 2022 (International Energy Agency 2022).

There is also evidence to suggest that transitions to hydrogen and hydrogen-based fuels such as ammonia could help reorganize the energy structure in Southeast Asia. Figure 6 shows the total demand for low-emission fuels in Southeast Asia in the SDS for the period 2000–2050. Brunei has begun exporting small amounts of hydrogen to Japan, while Indonesia, Malaysia, the Philippines, and Thailand are testing the use of green hydrogen. Malaysia and Indonesia are studying the possibility of using ammonia as a fuel in coal power plants with Japan, and both countries are working with Japan to develop hydrogen and ammonia supply chains. Thailand and Singapore are also pursuing similar initiatives. Some major oil and gas companies, including Petronas, Pertamina, and PTT, are planning investments in hydrogen supply chains (International Energy Agency 2022). In the above instances, it would be beneficial for Japan and partner countries to underline the synergies between projected investments in renewables and transitions to green hydrogen.

Figure 6: Total Demand for Low-Emission Fuels in Southeast Asia in the SDS, 2000–2050



Source: Southeast Asian Energy Outlook 2022 (International Energy Agency 2022).

Coherence with Japan's Local Revitalization Strategy

Though hydrogen has been viewed as a potential alternative for the energy demand in heavy industries and freight transport, it also has a role in local revitalization. This is particularly true as green hydrogen development can help achieve many socioeconomic and environmental goals at the local level. For example, the development of new technologies and the creation of new jobs in the hydrogen industry could help to stimulate economic growth and innovation. In addition, Japan has the potential to be a leader in green hydrogen production and can use this position to cooperate with other countries in the region and beyond to accelerate the global transition to clean energy. This could help to create new business and trade opportunities for Japanese companies and boost the country's economy.

The potential to deliver multiple benefits is already on display in some parts of Japan. To illustrate this, a local hydrogen society is gradually being developed in Shikaoi, Hokkaido. Shikaoi is a small town that relies heavily on dairy and upland farming activities. The town produces large amounts of livestock manure, using the excess manure to generate biogas and high-quality organic fertilizer. In 2015, Shikaoi began to develop a biogas-based hydrogen supply chain that produces, stores, transports, supplies, and uses hydrogen. Green hydrogen from this project is used for hydrogen for fueling vehicles. The project is now attempting to reduce emissions in the agriculture sector by powering agriculture vehicles with hydrogen energy. The project is still at the demonstration stage but intends to expand the demand and use of hydrogen in other activities such as dairy farming and vegetable warehousing within the region even after its completion (Ministry of the Environment of Japan 2019; Ministry of the Environment of Japan 2021).

Other examples from Japan also suggest the potential for greater coherence with local development plans. For instance, a demonstration project using P2G technology is already underway in Fukushima Prefecture. The project will help address seasonal fluctuations related to grid and adjustment capacity problems (METI 2017).

Beyond the specific case of Shikaoi and Fukushima, there is significant scope to support the promotion of green hydrogen with local revitalization efforts more generally. Japan's most recent Basic Environmental Plan emphasizes the concept of the Circulating and Ecological Sphere (CES). The CES is premised on the notion of integrating climate and biodiversity goals by relying more on local resources and optimizing resource flows between urban and rural areas. The emergence and spread of locally based hydrogen societies could mutually reinforce efforts to give shape and substance to the CES in Japan (Ortiz-Moya et al. 2021). These efforts could also help to popularize the concepts and their underlying principles in other parts of Asia, strengthening the alignment with Japan's international climate strategy.

5. JAPAN'S ROLE IN LEADING A HYDROGEN ECONOMY IN ASIA

Japan has the potential to lead a pathway towards a hydrogen economy in Asia due to a combination of its advanced technology and competitive manufacturing environment. First, Japan has a strong track record of investing in research and development (R&D) in hydrogen-related technologies, including electrolysis, fuel cell technology, and hydrogen storage. This has enabled the country to develop a range of key technologies that are critical for the production, storage, and use of hydrogen. For example, Japan has developed advanced electrolysis systems that are highly efficient and can produce hydrogen using renewable energy sources such as solar and wind. It has also developed fuel cell technologies that can convert hydrogen into electricity with high efficiency and low emissions.

Second, Japan has a competitive manufacturing environment that could accelerate the adoption of hydrogen technologies in the region. Japan has a well-developed industrial base and a strong tradition of innovation and technological leadership, which could make it an attractive partner for other countries in the region looking to adopt hydrogen technologies. In addition, Japan's relatively low labor costs and access to a large market could make it an attractive location for the production of hydrogen technologies, which could help to drive down costs and increase the competitiveness of these technologies globally.

Overall, Japan's advanced technology and competitive manufacturing environment position it well to lead the way in the transition to a hydrogen economy in Asia. However, it is important to note that this transition will require the cooperation and collaboration of a wide range of stakeholders, including governments, companies, research institutions, and civil society organizations. By working together, Japan and other countries in the region can accelerate the adoption of hydrogen technologies and contribute to the global effort to combat climate change.

Hydrogen Technology and Innovation: Japan's Leading Role in Asia

Innovation in hydrogen energy is driving the development of new technologies and methods for producing, storing, and using hydrogen as a fuel. This includes advancements in electrolysis, fuel cells, and hydrogen storage systems, as well as the development of new hydrogen-powered vehicles. In Asia, Japan has been playing an important role in the research and development aimed at making hydrogen more cost-effective and widely available as a clean energy source.

A recent study conducted by the International Energy Agency (IEA 2023) uses the published International Patent Families (IPFs) as a metric to measure patenting activities in different categories of hydrogen-related technologies. The analysis focuses on the global geography of hydrogen innovation by looking at the locations of applicants and inventors of IPFs for hydrogen-related technologies. Japan has the largest number of IPFs (see Table 1) in the hydrogen sector in the world. In the Asian region, though several countries have been shaping ambitious hydrogen development plans, they do not have a notable number of original inventions. Nonetheless, countries like the Republic of Korea and the PRC have been investing strongly in hydrogen technologies.

**Table 1: Revealed Technology Advantages in Hydrogen Technologies
by Value Chain Segments, 2011–2020**

	Share of All Hydrogen-Related IPFs	Production	Storage, Distribution, and Transformation	Industrial Applications
Japan	24%	20%	22%	28%
US	20%	19%	23%	19%
Germany	11%	10%	14%	12%
Rep. of Korea	7%	6%	5%	9%
France	6%	7%	9%	4%
PRC	4%	5%	3%	3%
Netherlands	3%	4%	2%	3%
UK	3%	3%	2%	2%
Switzerland	2%	2%	1%	2%
Canada	2%	2%	2%	1%

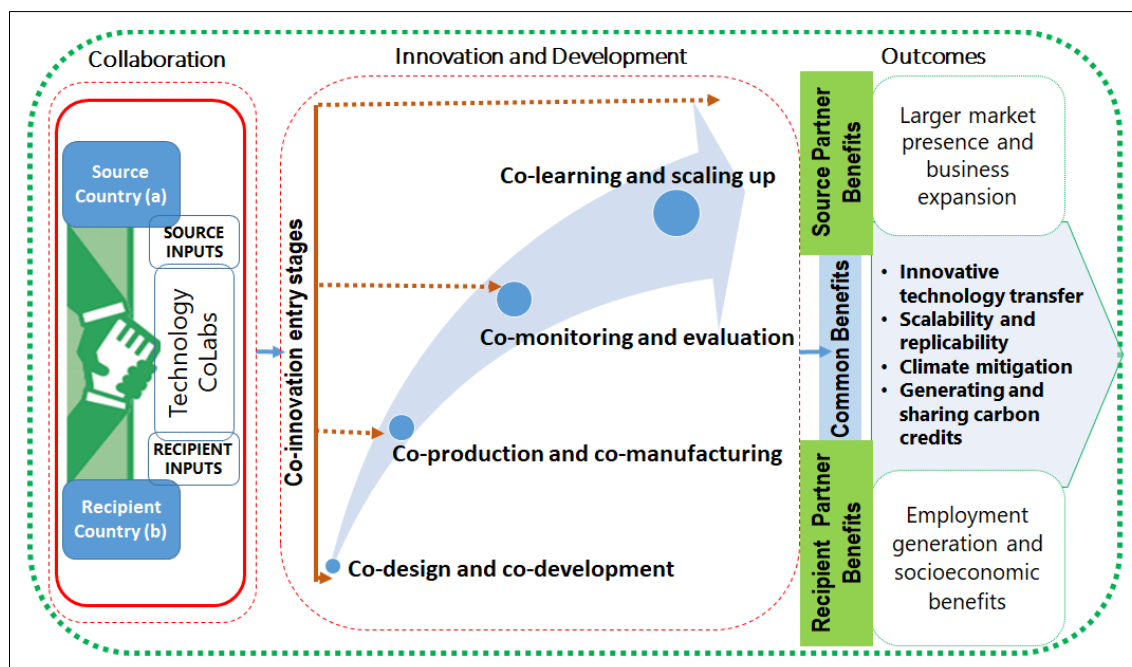
Source: (IEA 2023).

Japanese innovations can help to improve the efficiency and cost-effectiveness of hydrogen production, storage, and distribution, making it more competitive. Collaborating with Asian countries can help accelerate the transformation of Japan's hydrogen innovation into the production, storage, and application of technology in the region in several ways. By working together, Japan and other Asian countries can share their knowledge and expertise in hydrogen technology, leading to faster progress in areas such as hydrogen production and fuel cell development. Such collaborations can allow for more efficient use of resources, such as funding and infrastructure, and help to create economies of scale in the production and distribution of hydrogen. Working with countries like India, which have ambitious hydrogen development plans, can help to standardize and harmonize standards and regulations, which would increase the accessibility for countries to trade hydrogen and hydrogen-related products and services, boost the cooperation and interconnection of hydrogen infrastructure, and accelerate the deployment of hydrogen across Asia.

Can Co-innovation Help Boost Japan's Collaboration with Asian Economies in Developing Hydrogen?

Co-innovation is a collaborative process in which different organizations, such as companies, research institutions, and government agencies, work together to jointly innovate technology, and develop and produce new products and services. This approach can be particularly effective in the field of hydrogen production, as it allows different stakeholders to share knowledge, resources, and expertise in order to accelerate the development and commercialization of hydrogen technologies.

Figure 7: Co-innovation Framework



Source: (Janardhanan et al. 2020; Janardhanan et al. 2021).

There are several ways in which co-innovation can help Japan and other Asian countries to jointly innovate technology, and develop and produce hydrogen. First, co-innovation can facilitate the sharing of knowledge and expertise among different organizations, which can lead to more efficient and effective innovation. For example, companies can collaborate with research institutions to access specialized knowledge and expertise in areas such as electrolysis, fuel cell technology, and hydrogen storage. This can help to speed up the development and commercialization of hydrogen technologies, as well as reducing the costs and risks associated with innovation. Second, co-innovation can allow different organizations to share resources and infrastructure. Third, co-innovation can enable Japanese and other Asian companies to work together to share risks and rewards. Overall, co-innovation can be a powerful tool for Japan and other Asian countries to jointly innovate technology, and develop and produce hydrogen. By fostering collaboration and aligning incentives among different stakeholders, co-innovation can help to accelerate the transition to a hydrogen economy and contribute to the global effort to combat climate change.

6. RECOMMENDATIONS

The previous sections suggested that there are both considerable barriers and benefits to promoting a transition to green hydrogen for Japan. These include a stronger alignment with international climate strategies and local revitalization plans. At the same time, relevant national hydrogen policies and strategies have remained ambiguous on Japan's commitment to transitioning to green hydrogen. This could result in a lost opportunity for Japan. Several recommendations follow that can help Japan capitalize on this opportunity. The first recommendation is to provide greater clarity in national policies on the intention to support the transition to green hydrogen. This clarity can be demonstrated through the use of more precise language in relevant policy statements, as well as the inclusion of visible milestones that are consistent with timetables for nationally determined contributions (NDCs). In addition, policy statements should place a greater emphasis on transition pathways, rather than just one-off demonstration projects, in order to provide a clearer roadmap for the shift to green hydrogen. It is also important to highlight the climate benefits of green hydrogen in these policy statements and contrast them with the delays that can occur when transitioning to green hydrogen. There is evidence to support the effectiveness of such approaches: For instance, a study by the International Renewable Energy Agency (IRENA) found that clear, long-term policy frameworks and targets are key to increasing the deployment of renewable energy technologies, including hydrogen.

A second recommendation is to strengthen the connections between hydrogen policies and strategies and local revitalization plans. For example, supporting and showcasing successful demonstrations of hydrogen use, like those in Shikaoi town in Japan, can be helpful. Additionally, providing funding to support more demonstrations in areas that are focused on addressing climate change or climate-energy systems (CESSs) can be useful. Another suggestion is to offer localities stronger incentives to develop and implement their plans for locally relevant hydrogen societies, to scale up local experiments. Lastly, the national government should strengthen the necessary infrastructure to support the transportation of hydrogen fuels from rural to urban areas.

A third recommendation is to bring the same level of clarity and commitment to green hydrogen in international climate strategies. By expressing the intention to build a sustainable hydrogen supply chain, rather than just any hydrogen supply chain, countries can better align with regional decarbonization plans and encourage partner countries to see the value of strengthening connections between their renewable energy and green hydrogen plans. This can also be achieved by placing a greater emphasis on a mutually beneficial process of co-innovation, rather than one-way technology transfer. Establishing a hydrogen economy in Asia will require a functioning hydrogen market that enables cooperation and trade within the region and beyond. To capture the benefits of leadership in this market, it is essential to adopt a co-innovation process that facilitates and shares the benefits of the transition to green hydrogen.

A fourth recommendation is to allocate a significant portion of the funds pledged by the Japanese Prime Minister, Kishida, during CoP21 (Okutsu 2021), towards supporting the development and deployment of green hydrogen technologies in Asia. This can be achieved through collaboration with local governments and private sectors in the region, including joint research and development projects, technology transfer, and demonstration projects. To maximize the impact of these funds, it is important to prioritize projects that have the potential to scale up and achieve significant emissions reductions in the region. This funding can also be used to support capacity building in the region, such as training programs for policymakers, local engineers, and

technicians in green hydrogen technologies, and to support the development of necessary infrastructure for green hydrogen production and transportation.

A fifth recommendation pertains to countries outside Japan. Several countries in developing Asia have been shaping strategies to include hydrogen in their energy mix. Developing countries in Asia would be well advised to reinforce these domestic efforts by establishing agreements for joint research and development, technology transfer, and investment in the hydrogen sector. These agreements could include the exchange of technical knowledge, funding support, and sharing best practices. Additionally, developing countries in Asia can work together with Japan to promote regional cooperation in the hydrogen sector. This could include establishing a regional hydrogen market, sharing infrastructure for hydrogen production and distribution, and coordinating policy approaches to support the deployment of hydrogen technologies. Moreover, developing countries in Asia can collaborate with Japan to develop a joint roadmap for the development of the hydrogen sector in the region. This roadmap could include specific targets, timelines, and actions to promote the deployment of hydrogen technologies and infrastructure.

These efforts can help developing countries in Asia to not only benefit from Japan's advanced technology and expertise in green hydrogen but also to build stronger collaboration in the region for the deployment of hydrogen technologies. The policy takeaway for these countries is the importance of having a clear roadmap for the deployment of hydrogen technologies and infrastructure, establishing strong policy frameworks, and promoting regional cooperation to build a sustainable hydrogen economy. Further, collaborating with advanced countries like Japan can help them leapfrog in the development of green hydrogen technologies and provide access to funding and technical expertise.

7. CONCLUSION

The idea of a hydrogen society in Asia is gaining traction in international policy circles and particularly in Japan. The growing interest makes sense for Japan: It is an industrially advanced economy with a strong track record of investing in hydrogen-related research and development, and it has the potential to lead the way in the large-scale commercialization of, and collaboration on, hydrogen in the region. As an industrially advanced economy, it has already invested in hydrogen-related R&D and developed key hydrogen-related technologies (Otsuki et al. 2019; Janardhanan et al. 2021). Japan's advanced technology, combined with the competitive manufacturing environment in developing countries in Asia, could accelerate the transition to a hydrogen society in the region. However, a lack of clarity about the transition to green hydrogen could hinder efforts to use hydrogen to meet ambitious climate targets. This paper recommends a set of policies for Japan to consider in its national and regional efforts to promote the use of hydrogen in Asia. While the focus of this paper is on Japan, many of these recommendations apply to other countries in and outside of Asia. By embracing greater clarity about the transition to green hydrogen, countries have the opportunity to benefit both the planet and its inhabitants.

REFERENCES

- Aditiya, H. and Aziz, M., 2021. Prospect of hydrogen energy in Asia-Pacific: A perspective review on techno-socio-economy nexus. *International Journal of Hydrogen Energy*, 46(71), pp. 35027–35056.
- Atilhan, S. et al., 2021. Green hydrogen as an alternative fuel for the shipping industry. *Current Opinion in Chemical Engineering*, 31(100668).
- BBC, 2021. *Hydrogen power offers jobs boost, says government*. [Online] Available at: <https://www.bbc.com/news/science-environment-58238367> [Accessed 10 July 2022].
- CoP UK2021, 2021. *Global Coal to Clean Power Transition Statement*. [Online] Available at: <https://ukcop26.org/global-coal-to-clean-power-transition-statement/> [Accessed 15 April 2023].
- Government of UK, 2021. *UK government launches plan for a world-leading hydrogen economy*. [Online] Available at: <https://www.gov.uk/government/news/uk-government-launches-plan-for-a-world-leading-hydrogen-economy> [Accessed 20 August 2022].
- Howarth, R. W. and Jacobson, M. Z., 2021. How green is blue hydrogen?. *Energy Science and Engineering*, p. <https://doi.org/10.1002/ese3.956>.
- Hydrogen Council, 2021. *Hydrogen Insights: A perspective on hydrogen investment, market development and cost competitiveness*, Brussels: Hydrogen Council & McKinsey & Company.
- Hydrogen Council, 2021a. *Hydrogen Investment Pipeline Grows To \$500 Billion In Response To Government Commitments To Deep Decarbonisation*. [Online] Available at: <https://hydrogencouncil.com/en/hydrogen-insights-updates-july2021/> [Accessed 15 July 2022].
- IEA, 2019. *The Future of Hydrogen*, Paris: International Energy Agency.
- , 2022. *Global Hydrogen Review*, Paris: IEA.
- , 2023. *Hydrogen patents for a clean energy future*, Paris: International Energy Agency.
- International Energy Agency, 2022. *Southeast Asia Energy Outlook 2022*, s.l.: International Energy Agency.
- , 2022. *Southeast Asia Energy Outlook 2022*, s.l.: International Energy Agency.
- , 2022. *Southeast Asia Energy Outlook 2022*, Paris: International Energy Agency.
- IPCC, 2018. *The evidence is clear: the time for action is now. We can halve emissions by 2030*. [Online] Available at: <https://www.ipcc.ch/2022/04/04/ipcc-ar6-wgiii-pressrelease/> [Accessed 11 01 2023].
- IRENA, 2022. *Global hydrogen trade to meet the 1.5°C climate goal: Part III – Green hydrogen cost and potential*, Abu Dhabi: International Renewable Energy Agency (IRENA).
- Janardhanan, N. et al., 2021. *Potential for Japan-India Co-Innovation for Hydrogen Development: Partnerships for National and Global Wins*, Hayama: Institute for Global Environmental Strategies.

- Janardhanan, N., Ikeda, E., Zusman, E. and Tamura, K., 2020. *Co-innovation for Low Carbon Technologies: The Case of Japan-India Collaboration*, Hayama: Institute for Global Environmental Strategies.
- Janardhanan, N., Pham, N.-B., Hibino, K. and Akagi, J., 2021. Japan's low-carbon technology collaboration with Southeast Asia: Co-innovation and Co-benefits. In: H. Farzaneh, E. Zusman and Y. Chae, eds. *Aligning Climate Change and Sustainable Development Policies in Asia*. Singapore: Springer, pp. 10–25.
- Khan, U., Yamamoto, T. and Sato, H., 2021. An insight into potential early adopters of hydrogen fuel-cell vehicles in Japan. *International Journal of Hydrogen Energy*, 46(2021), pp. 10589–10607.
- KPMG, 2020. The hydrogen trajectory: What does research tell us about the pace of development of hydrogen technologies?. *KPMG Insights*.
- METI, 2017. *Basic Hydrogen Strategy*. [Online] Available at: https://www.meti.go.jp/english/press/2017/pdf/1226_003a.pdf [Accessed 17 May 2020].
- Ministry of Economy, Trade and Industry, 2021. *Ideal Energy Policy towards 2030*, Tokyo: Ministry of Economy, Trade and Industry, Japan.
- , 2022. *Transition Roadmap in the Power Sector*, Tokyo: Ministry of Economy, Trade and Industry, Japan.
- Ministry of the Environment of Japan, 2019. 事例6 北海道鹿追町 ～家畜ふん尿由来の水素を活用した水素サプライチェーンモデルの構築～(Case 6 Shikaoi Town, Hokkaido -Construction of a hydrogen supply chain model utilizing hydrogen derived from livestock manure). In: *地域循環共生圏事例集: 脱炭素化・SDGsの実現に向けた日本のビジョン (Regional Circulation Symbiotic Area Casebook: Toward the realization of decarbonization and SDGs Japan's vision)*. Tokyo: Ministry of the Environment of Japan.
- , 2021. *The hydrogen energy supply chain demonstration project from livestock manure (Shikaoi Town and Obihiro City, Hokkaido, Primary partner: Air Water Inc.)*. [Online] Available at: https://www.env.go.jp/seisaku/list/ondanka_saisei/lowcarbon-h2-sc/en/demonstration-business/PDF/pj02_211124.pdf [Accessed 07 5 2023].
- Ministry of Trade, Industry and Energy, 2020. *Hydrogen Economy Roadmap of Korea*, Seoul: Ministry of Trade, Industry and Energy.
- MNRE, 2021. *Provisions for RE Sector in the Annual Budget 2021-22*. [Online] Available at: https://mnre.gov.in/img/documents/uploads/file_f-1612941710983.pdf [Accessed 12 November 2021].
- Nakano, J., 2021. *Japan's Hydrogen Industrial Strategy*. [Online] Available at: <https://www.csis.org/analysis/japans-hydrogen-industrial-strategy> [Accessed 12 November 2021].
- Ohta, T. and Abe, I., 1985. Hydrogen energy research and developments in Japan. *International Journal of Hydrogen Energy*, 10(5), pp. 275-279.
- Okutsu, A., 2021. *Japan pledges extra \$10bn of overseas climate financing*. [Online] Available at: <https://asia.nikkei.com/Spotlight/Environment/Climate-Change/COP26/Japan-pledges-extra-10bn-of-overseas-climate-financing> [Accessed 15 April 2023].

- Ortiz-Moya, F. et al., 2021. Sustainable transitions towards a resilient and decentralised future: Japan's Circulating and Ecological Sphere (CES). *Sustainability Science*, 31 3. Volume 1.
- Otsuki, T., Komiyama, R. and Fujii, Y., 2019. Possibility of introducing hydrogen as fuel for power generation and automobiles: Analysis using a regional subdivided world energy system model. *Journal of the Japan Energy Society*, 98(4), pp. 62–72.
- Panchenko, V. et al., 2023. Prospects for the production of green hydrogen: Review of countries with high potential. *International Journal of Hydrogen Energy*, 48(12), pp. 4551-4571.
- PIB, 2023. *Cabinet approves National Green Hydrogen Mission*. [Online] Available at: <https://pib.gov.in/PressReleaseDetailm.aspx?PRID=1888545> [Accessed 05 January 2023].
- Reuters, 2021. *Japan allocates up to \$3.4 bln from green fund to accelerate R&D in hydrogen* | Reuters. s.l.:s.n.
- Thorpe, D., 2016. *The hydrogen economy is much nearer than we think*. [Online] Available at: <https://energypost.eu/hydrogen-economy-much-nearer-think/>