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DECARBONIZING ASIAN ECOMONIES WITH GREEN HYDROGEN

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EXECUTIVE SUMMARY

Introduction

Hydrogen has gained global attention as a key breakthrough for decarbonizing hard-to-abate sectors. Low-carbon hydrogen can be produced from a wide range of resources. This diversity of sources enables hydrogen production almost anywhere in the world.

The ASEAN region is struggling to set and achieve ambitious decarbonization goals. The development of a green hydrogen economy in the ASEAN region can contribute to accelerated region-wide transition to clean and sustainable energy, and thus the decarbonization of the region's economy. However, the region has yet to harness its great potential for renewable power, much less green hydrogen production.

This study analyzes the potential of using green hydrogen produced in the ASEAN region to decarbonize sectors - hard-to-abate industries and transport - for which electrification is not the optimal solution.

Green hydrogen supply and demand potential in the ASEAN region

Based on IEA (2022b) and projections for 2050, potential hydrogen demand was determined by assuming that renewable power would be used in all sectors that can be electrified and that the remaining hard-to-abate applications would be covered by green hydrogen. High-temperature heat demand in the industry sector and part of the transport sector (heavy-duty vehicles, and air, maritime, and rail transport) were included in the study.

Despite energy efficiency improvements, energy consumption will increase significantly in both the industry and transport sectors in 2050, driven by economic growth. The potential hydrogen demand of the entire ASEAN region is 152 Mtoe, or 40% of total final energy consumption across the industry sector. The potential hydrogen demand in the transport sector across the entire ASEAN region is 166 Mtoe, accounting for 44% of final energy consumption in the transport sector.

Since increased renewable power deployment should be prioritized in the ASEAN region, potential hydrogen supply was evaluated under the assumption that renewable energy would primarily be used to replace fossil fuel-fired thermal power plants, only after which the remaining renewable power would be used to produce hydrogen. Based on the renewable energy potential provided in ERIA (2021) and IRENA & ACE (2022), the authors derived the regional potential for green hydrogen production.

Even under the assumption that renewable energy would cover both total power generation in 2050 and the additional power generation needed to accommodate further electrification demand in 2050 and beyond, surplus renewable energy is available for use in hydrogen production. ASEAN countries collectively have the potential to supply three times the potential hydrogen demand in 2050 (Figure). Therefore, even in the most pessimistic case, there is an ample potential supply of green hydrogen across the entire ASEAN region to cover regional hydrogen demand. Therefore, the intra-regional trade of green hydrogen could offer a solution to the challenge of region-wide decarbonization of hard-to-abate industries using local resources.

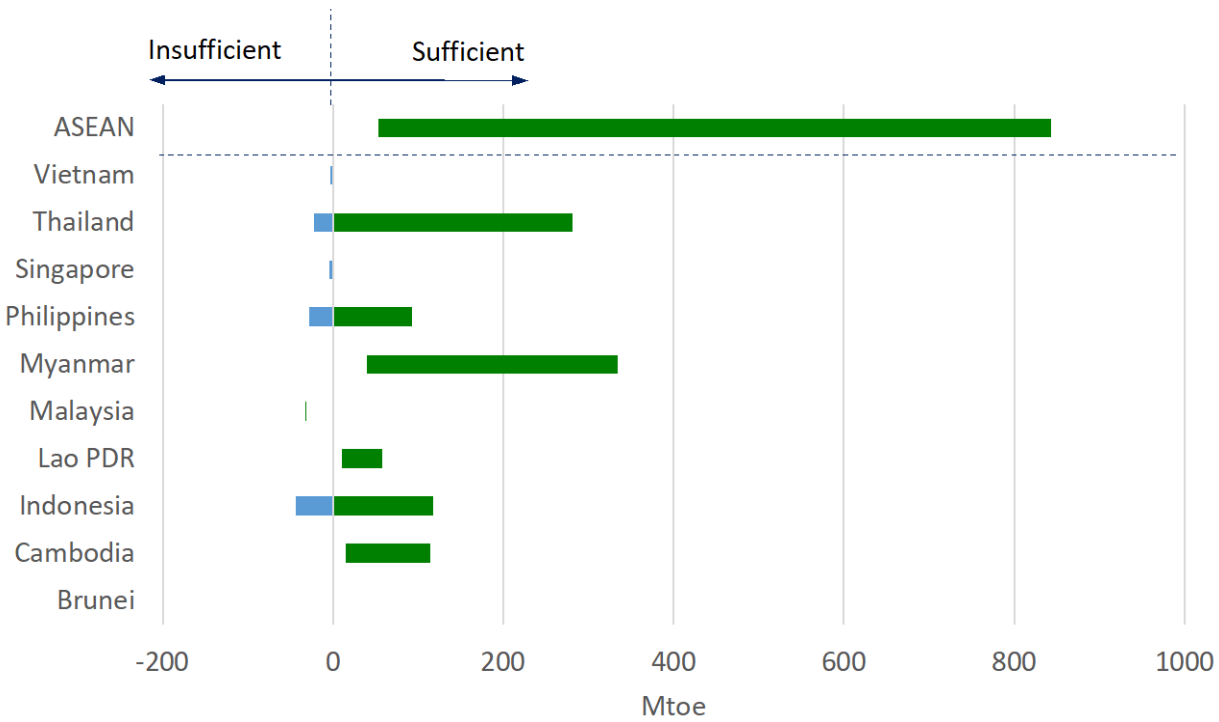

FIGURE. SUFFICIENCY OF POTENTIAL GREEN HYDROGEN SUPPLY (2050)

Opportunities and challenges for the ASEAN region

Green hydrogen production may change the geopolitics of the ASEAN region to some extent. Low-income economies, such as Myanmar, Lao PDR, and Cambodia, will have the opportunity to become the region's energy supplier. However, most ASEAN member countries have yet to develop national hydrogen strategies, or even include hydrogen in their national energy plans. Furthermore, there are various challenges to developing the full renewable energy potential of the region. These include the lack of financial support and channels, lack of experience and regulatory frameworks, insufficient coordination among government agencies, and limited infrastructure, such as grid enhancement needs for massive renewable integration. The power development plans and renewable power targets laid out by each country also fall substantially short of their renewable energy potential. Therefore, policy measures will need to be put in place to harness their full potential.

Home to very limited energy resources, Japan is likely to continue to be an energy importer even in the hydrogen era. The ASEAN region, given its proximity, is potentially a promising major supplier of green hydrogen for Japan, which aims to introduce 3 million tonnes of hydrogen in 2030 and 20 million tonnes in 2050. Not only is its proximity an advantage, but green hydrogen imports from the ASEAN region will also contribute to diversifying its energy imports, and thus serve Japan's energy security.

Another consideration to be made is Singapore's global importance as a bunkering hub, supplying almost 50 million tonnes of marine bunker fuel to vessels in 2021. A reasonable amount of regionally produced e-fuel can be collected in Singapore from across the ASEAN region. This can potentially offer large business opportunities for the ASEAN region.

Further promoting renewable energy development

For green hydrogen to be a realistic and optimal solution for decarbonizing the economy, the renewable power used in its production should be available in surplus, after being fully harnessed to decarbonize sectors whose carbon footprint can be lowered by using it directly. Therefore, investment should first be targeted at developing renewable energy. To support this, it is essential that polices are in place for the massive deployment of renewable energy in each country. This will help lower renewable power generation costs and in turn bring down green hydrogen production costs, which is most affected by power generation costs (IEEJ, 2021).

Japan's role

Japan can play an important role in building and expanding the regional hydrogen market and thus bring costs down through close cooperation with ASEAN countries on hydrogen-related technology development. Since the renewable energy market is yet to be fully developed in some countries, players may be able to enjoy first-mover advantage in establishing the business environment for renewable energy, and in turn for hydrogen. Japan's experience with relevant infrastructure, transportation and storage technologies, laws and regulation, and safety standards can help develop ASEAN's regional hydrogen market.

The year 2023 marks the "50th Year of ASEAN-Japan Friendship and Cooperation." Japan has built many cooperation frameworks in place for supporting ASEAN countries' energy transition. Under these frameworks, Japan can also support the designing of aggressive but feasible decarbonization policies with consideration of region-specific circumstances and needs. Such support could include technological and financial support, in-depth studies to reveal local challenges and solutions, support in formulating master plans based on such studies, and the implementation of stakeholder dialogue.

CHAPTER 1. BACKGROUND AND OBJECTIVES OF STUDY

Given the urgent call to globally reduce CO_2 emissions to net-zero by mid-century (IPCC, 2021), many countries in the ASEAN region are struggling to set and achieve ambitious decarbonization goals. Renewable energy and low-carbon hydrogen are key to decarbonizing their economies. The ASEAN region bears great potential for renewable power, including solar, wind, and hydropower. These resources can be used to produced green hydrogen, but this potential has yet to be sufficiently explored. The development of a green hydrogen economy in the ASEAN region can contribute to accelerating region-wide transition to clean and sustainable energy and raising its energy self-sufficiency, and in turn enhancing the region's energy security.

Low-carbon hydrogen can generally be produced from a wide range of resources. This diversity enables hydrogen production almost anywhere in the world. Yet, home to very limited energy resources, Japan will need to rely heavily on imports for hydrogen as well. Due to its proximity, the ASEAN region could promise to be a future supplier of hydrogen to Japan, depending on its potential.

In Japan, discussions on procuring hydrogen started in 2012, the year following the Great East Japan Earthquake, when the country was faced with challenges in decarbonizing its energy system, especially in terms of power generation. Japan continues to be challenged with social acceptance issues and land constraints in increasing nuclear power generation and massively deploying renewables. While Japan has made significant efforts to increase its renewable capacity, its critically low renewable energy potential stands out in the global context (IRENA, 2021b). Therefore, having considered hydrogen to be a breakthrough for decarbonization from a very early time, Japan was the first country in the world to formulate a national hydrogen strategy[1] and seeks to create hydrogen demand of approximately 20 million tonnes in 2050[2].

The recent enthusiasm of the Japanese government and private sector has been inclined towards importing blue hydrogen or blue fuel ammonia. However, this study will focus on green hydrogen for reason explained in Section 2.1.

This study will explore the ASEAN region's potential for using locally produced green hydrogen to decarbonize its economy, focusing on its application in industry and transport. It will also look at its potential to become a hydrogen exporter to areas outside the region, such as Japan.

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[1] Ministry of Economy, Trade and Industry, Japan (2017) Basic Hydrogen Strategy

[2] Ministry of Economy Trade and Industry, Japan (2020) "Green Growth Strategy Through Achieving Carbon Neutrality in 2050," https://www.meti.go.jp/english/press/2020/1225_001.html

Chapter 2. Scope of study and methodology

2.1. Scope of study

This study analyzes the potential of using green hydrogen produced in the ASEAN region to decarbonize sectors in which electrification is not the optimal solution. These include hard-to-abate industries and parts of the transport sector.

The authors focus on green hydrogen, or hydrogen produced via water electrolysis using renewable energy sources, including solar power, wind power, hydropower, geothermal power, and biomass. Some ASEAN countries are home to fossil fuel resources and thus countries like Brunei and Malaysia currently host projects to build international supply chains for blue hydrogen, produced from fossil fuels but with the carbon generated during the process captured and stored. However, this study does not consider blue hydrogen despite its availability for several reasons:

First, given its smaller carbon footprint, green hydrogen will not be challenged by the increased market and political pressure against using fossil fuels. Second, the recent energy crisis has revealed challenges and disadvantages inherent to blue hydrogen. The price of blue hydrogen and its derivatives risk being affected by volatile market fossil fuel prices, which can surge as witnessed in the past year[3]. Skyrocketing oil and gas prices may make green hydrogen increasingly competitive and attractive, as renewable energy prices have consistently dropped regardless of oil and gas market trends. Third, renewable energy can be found in a wider area and thus any country can become a green hydrogen exporter by harnessing such resources. While blue hydrogen would be imported from oil and gas producing countries, green hydrogen supply chains can be more diversified, reaching beyond conventional energy exporters, and thus contribute to improving the region's energy security.

2.2. Methodology

2.2.1. Potential hydrogen demand

Hydrogen can technically be used for a wide variety of applications. However, it is unreasonable to apply hydrogen when more cost-efficient solutions are available. Therefore, this study assumes that hydrogen will be used in "hard-to-abate" sectors that are difficult to decarbonize through electrification. Potential hydrogen demand was determined by assuming that all hard-to-abate applications would be covered by green hydrogen. The following hard-to-abate applications were

[3] For example, the Fuel Ammonia Supply Chain Public-Private Task Force, METI (2022) analyzed that when gas prices increase by USD0.5/mmbtu, ammonia prices increase by USD18/t-NH3.

considered: high-temperature heat demand in the industry sector; and heavy-duty vehicles, and air, maritime, and rail transport in the transport sector. Some past studies (e.g. ERIA, 2019) have given great consideration to using hydrogen in the power generation sector. However, the ASEAN region has yet to unleash its renewable energy potential and should prioritize renewable power deployment toward 2050. Only after the power generation sector has been decarbonized by renewable power, should surplus renewable grid power or unharnessed renewable energy be used for hydrogen production. Hence, this study did not consider hydrogen use in the power generation sector.

This study will evaluate potential hydrogen demand based on current final energy demand and projections for 2050 using the following methodology:

(1) Industry sector

i. Based on IEA (2022b), final energy demand in the industry sector in 2019 is identified for each ASEAN country by industry and by energy type.
ii. Based on an existing study (MRI, 2018), the share of high temperature (≥400°C) heat demand against total fossil fuel consumption is identified for each industrial sector (Table 1). Although MRI (2018) analyzes Japanese industry, this study assumes that the energy consumption structure in each industrial sector is not varied among different countries.
iii. Potential hydrogen demand is estimated by multiplying the total fossil fuel consumption in each industrial sector by the abovementioned sector-specific ratio. It should be noted that although heat demand comprises heating (burners) and steam production (boilers), the same conversion efficiency is assumed for fossil fuel-based burners/boilers and hydrogen burners/boilers.

TABLE 1. SHARE OF ≥400°C HEAT DEMAND IN FOSSIL FUEL CONSUMPTION BY INDUSTRY

Iron and steel	98%
Chemical and petrochemical	33%
Non-ferrousmetals	98%
Non-metallicminerals	92%
Transport equipment	44%
Machinery	44%
Food and tobacco	12%
Paper,pulp and printing	58%
Wood and wood products	58%
Textile and leather	5%
Industry not elsewhere specified	44%

Source: MRI (2018)

(2) Transport sector

i. Based on IEA (2022b), final energy demand in 2019 is identified for each ASEAN country by mode of transportation.
ii. For road transport, it is assumed that light-duty vehicles run on gasoline and LPG and will be converted to battery electrical vehicles (BEVs). Therefore, they are excluded from the current study. Heavy-duty vehicles are assumed to run on diesel. Heavy-duty trucks and buses that are fueled with diesel today are likely to be replaced by fuel-cell electric vehicles (FCEVs) from the perspectives of travel distance and carrying capacity.
iii. Likewise, all fuels used in air, maritime, and rail transport represent potential hydrogen demand. However, it should be noted that synthesized fuels (e-fuel) produced from hydrogen may be chosen for these modes of transportation.
iv. The fuel efficiency of fuel cell trucks and buses vary depending on the vehicle type and capacity and can thus be larger or smaller than that of diesel vehicles. Hence, the same fuel efficiency is assumed for FCEVs and diesel vehicles. The same assumptions are applied for air, maritime, and rail transport[4].

Based on the abovementioned methodology, potential hydrogen demand in the industry and transport sectors in 2019 are estimated. Potential hydrogen demand in 2050 is estimated by multiplying the potential hydrogen demand in 2019 by the ratio of final energy consumption in the industry and transport sectors in the ASEAN region in 2050 to that in 2019 as forecasted in ERIA (2021). Assuming that hydrogen will be introduced after low-carbon technologies commercialized today have been deployed, estimations are based on the Alternative Policy Scenario (APS) which projects advancements in low-carbon technology deployment, instead of business-as-usual (BAU).

2.2.2. Potential hydrogen supply

Given that increasing renewable power generation should be prioritized in the ASEAN region, potential hydrogen supply was evaluated under the assumption that renewable power generation would primarily be used to replace fossil fuel-fired thermal power generation, after which the remaining

4 The fuel efficiency of conventional diesel-powered buses and trucks is 3.6~9.1 MJ/km and 3,.6~19 MJ/km (estimated by author based on data from Ministry of Land, Infrastructure, Transport and Tourism, Japan; https://www.mlit.go.jp/jidosha/jidosha_fr10_000044.html), respectively, and that of FCEVs is 9 MJ/km (converted from 7.5kg-H2/100km (Hydrogen LHV: 120MJ/kg); Data source: Hydrogen Europe, "Green Hydrogen Investment and Support", P.26, https://profadvanwijk.com/wp-content/uploads/2020/05/Hydrogen-Europe_Green-Hydrogen-Recovery-Report_final.pdf). A more detailed evaluation would require consideration of the different efficiency levels of each vehicle type.

renewable power could be used to produce hydrogen. The methodology provided below was followed for the evaluation:

i. Renewable energy potential (potential installed capacity)[5] is estimated from existing studies (ERIA, 2021; IRENA & ACE, 2022).
ii. The capacity factor of renewable power generation in each ASEAN country is derived from IRENA Data & Statistics to calculate renewable energy potential (potential power output).
iii. Potential hydrogen supply is estimated based on the assumption that the renewable power remaining after deduction of the 1) total power generation in 2050 and 2) additional power generation needed to account for the electrification of certain final fossil fuel consumption in 2050 and beyond (in other words, final fossil fuel consumption less what can be replaced with hydrogen, or the potential hydrogen demand in the industry and transport sector estimated above) from renewable energy potential (TWh). Final energy consumption in 2050 is derived from APS projections in ERIA (2021). Fossil fuel-fired thermal power generation abated using carbon capture and storage (CCS) is likely to account for a part of total power generation; and therefore, the assumption that all power generation will be covered by renewable energy results in a conservative estimate of potential hydrogen supply. The electric power required to replace fossil fuel consumption is calculated using given conversion efficiency factors[6]. Producing hydrogen with electrolysis requires 4.5 kWh/Nm^3-H_2=50.4 kWh/kg-H_2.
iv. It should be noted that hourly renewable energy output variability has not been considered when estimating the surplus power available.

5 Here, “potential” refers to the technical potential of renewable energy, which applies technology characteristics and land eligibility constraints to their theoretical potential. Economic considerations have not been made. Details of the constraints considered vary among different studies.

6 In the industry and residential sectors, the efficiency of fossil fuel-based equipment and electrical appliances are assumed to be 80% and 90%, respectively. In the transport sector, the efficiency of conventional vehicles and electric drive vehicles are assumed to be 0.5 km/MJ and 2.8 km/MJ, respectively.

Chapter 3. Major findings

3.1. Review of climate and hydrogen policies in ASEAN member countries

3.1.1. A review of climate policies

Most countries in the ASEAN region have announced their ambitions to achieve carbon neutrality in around 2050 yet face many challenges in achieving this goal. Carbon neutrality goals are supported by nationally determined contributions (NDCs), many of which have been updated over the past two years. Indonesia, the Philippines, Thailand, and Vietnam have included more ambitious conditional targets that can be achieved by sufficient support from developed countries.

Besides Singapore and Brunei Darussalam, which do not have coal-fired power plants in their electric power systems, Vietnam has pledged to phase out coal by the 2040s. Cambodia, Indonesia, and the Philippines have also announced that they will not invest in new coal-fired power plant projects. These countries plan to increase uptake of natural gas and introduce renewable energy in the long run. (Appendix 1 provides a table of carbon neutrality goals, greenhouse gas reduction targets, and coal phase-out policies in the ASEAN region.)

3.1.2. Renewable energy targets

Figure 1 presents the shares of different energy sources in the primary energy mix in each ASEAN member country. All countries except for Myanmar rely heavily on fossil fuels. Biomass dominates the renewable energy portion of the energy mix in all countries. Indonesia and the Philippines also rely on geothermal energy (8% and 16% of the primary energy mix, respectively). Solar power and wind power currently account for less than 1% in all countries.

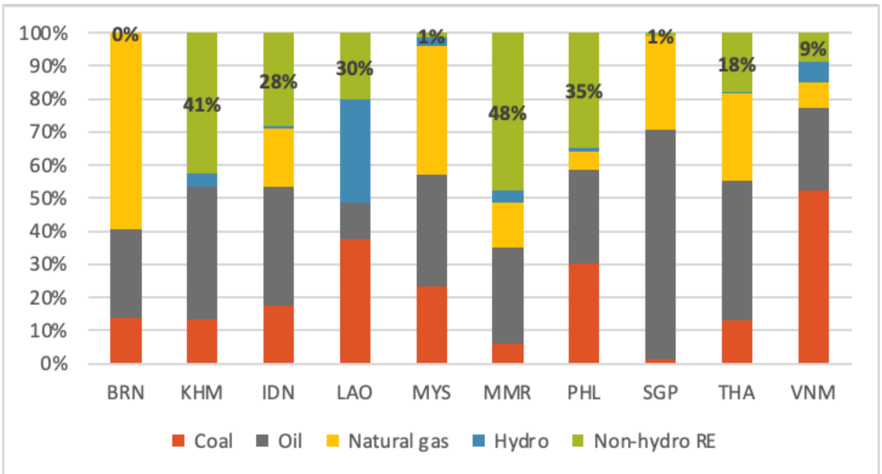

FIGURE 1. PRIMARY ENERGY MIX IN ASEAN MEMBER COUNTRIES (2020)

Source: compiled by authors based on IEA (2022b)

Note:

1) The country codes used are as follows: Brunei Darussalam (BRN), Cambodia (KHM), Indonesia (IDN), Lao DPR (LAO), Malaysia (MYS), Myanmar (MMR), the Philippines (PHL), Singapore (SGP), Thailand (THA), and Vietnam (VNM)
2) The labeled percentages represent the share of non-hydro renewable energy in the primary energy mix.

All ASEAN member countries have set up targets for increased renewable energy deployment (Appendix 2 provides details on renewable energy targets for each country). Countries that have recently updated their energy policy have adopted more ambitious targets. Most countries will rely greatly on massive deployment of solar PV to meet their targets. Indonesia, the Philippines, and Vietnam seek also to introduce offshore wind power in the longer term.

3.1.3. Hydrogen policies and roadmaps

Hydrogen has been mentioned in many national energy development plans as a promising emerging technology that will support decarbonization. Yet, only Singapore has set out a hydrogen strategy. Some countries are in the process of formulating hydrogen strategies or roadmaps. Other countries have announced studies and pilot projects at the corporate level. Indonesia's National Energy Plan (RUEN) includes a general action plan for hydrogen development and Malaysia's National Energy Policy 2022-2040 includes initiatives to formulate a hydrogen roadmap, a national strategy, and relevant regulations. It also aims to establish an internationally competitive hydrogen energy hub in Sarawak in the long term (2031-2040). Brunei has concluded Memoranda of Understanding (MOUs) with Asian countries such as Japan and Singapore on cooperation on building a hydrogen supply chain. (Appendix 3 provides for more details on hydrogen-related policies by country.)

3.2. The role of hydrogen in decarbonizing hard-to-abate industries and transport in ASEAN countries

Because of its potential as a feedstock, energy carrier and storage medium, green hydrogen promises to be key to decarbonizing many sectors of the economy. As a fuel, hydrogen can be used in: a) fuel cell vehicles in the transport sector, b) power generation (starting with co-combustion of hydrogen with gas or ammonia with coal and gradually shifting to 100% hydrogen), and c) in boilers and furnaces in the industrial sector.

As aforementioned, this study focuses on the potential of using hydrogen in decarbonizing hard-to-abate industrial processes and transport, which promise to have an economy-wide impact. Hydrogen use in the electric power sector is not considered as the study assumes that renewable energy will primarily be used for power generation. It should also be noted that replacing conventional grey hydrogen applications have not been considered.

3.2.1. Industries

Potential hydrogen demand in the industry sector is exhibited by country in Figure 2. Despite improvements in energy efficiency, energy consumption in the industry sector will increase significantly in 2050 driven by economic growth. By country, potential hydrogen demand is largest in Indonesia (62 Mtoe), followed by Vietnam (39 Mtoe), Thailand (22 Mtoe), and Malaysia (12 Mtoe). The potential hydrogen demand of the entire ASEAN region is 152 Mtoe, equivalent to 40% of total final energy consumption across the industry sector.

By industry, the cement industry, followed by the iron and steel industry, has the largest potential in hydrogen supply. In the iron and steel industry, potential hydrogen demand can include not only high-temperature heat demand, but also hydrogen use in direct reduction iron (DRI) processes resulting from conversion from conventional coke-fired blast furnaces. However, while blast furnaces may be introduced in the future, the ASEAN region currently relies mainly on electric arc furnaces; and therefore, this study does not consider the use of hydrogen as a reductant substitute. Potential hydrogen demand in the cement and iron and steel sectors is largest in Indonesia, Vietnam, and Thailand.

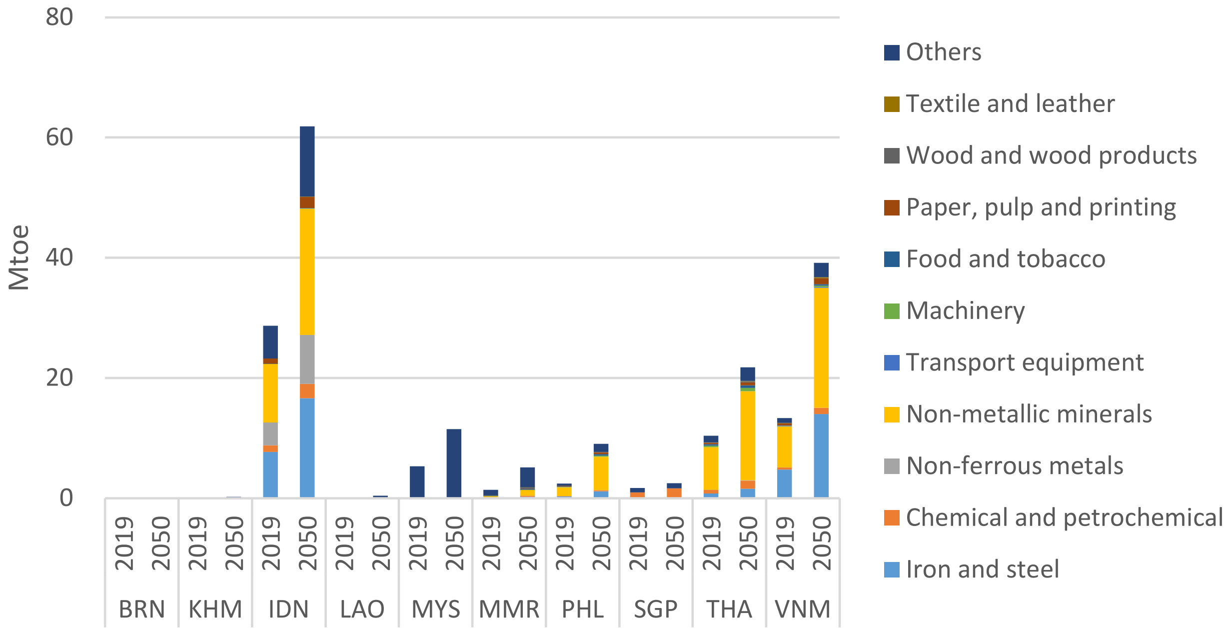

FIGURE 2. POTENTIAL INDUSTRY HYDROGEN DEMAND (2019 AND 2050)

Note:

The country codes used are as follows: Brunei Darussalam (BRN); Cambodia (KHM), Indonesia (IDN); Lao DPR (LAO); Malaysia (MYS); Myanmar (MMR); the Philippines (PHL), Singapore (SGP); Thailand (THA); and Vietnam (VNM)

3.2.2. Transport

Potential hydrogen demand in the transport sector is presented by country in Figure 3. Hydrogen demand will increase in 2050 with increased energy consumption in the transport sector driven by economic growth. Given its large population, Indonesia is home to the largest potential hydrogen demand, which will be 73 Mtoe in 2050. This is followed by Vietnam (29 Mtoe), Malaysia (21 Mtoe), the Philippines (19 Mtoe), and Thailand (12 Mtoe). The potential hydrogen demand in the transport sector across the entire ASEAN region is 166 Mtoe, accounting for 44% of final energy consumption in the sector. By mode of transportation, road transport (vehicles) accounts for approximately 80% of the total potential hydrogen supply.

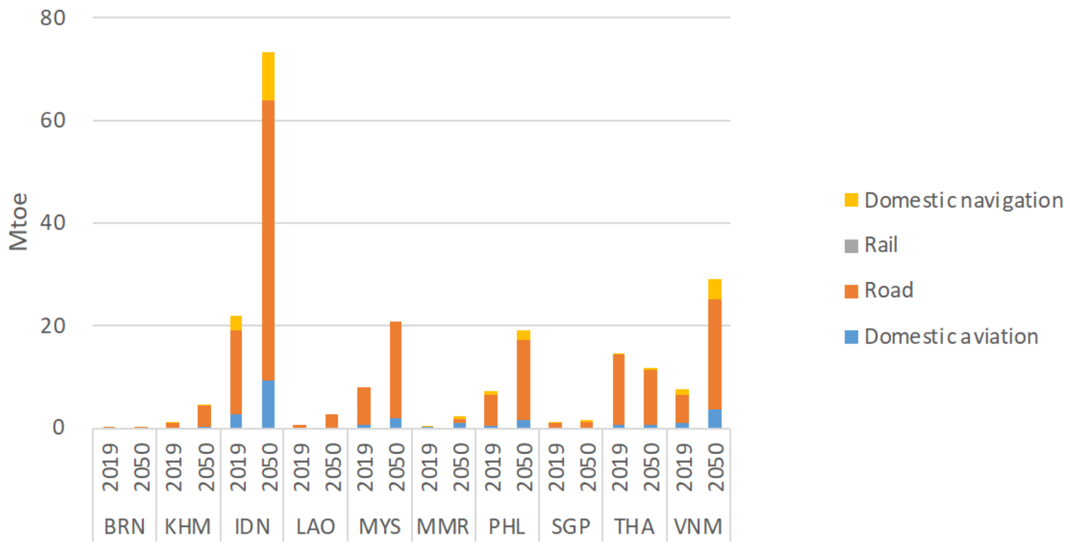

FIGURE 3. POTENTIAL TRANSPORT HYDROGEN DEMAND (2019 AND 2050)

Note:

The country codes used are as follows: Brunei Darussalam (BRN), Cambodia (KHM), Indonesia (IDN), Lao DPR (LAO); Malaysia (MYS), Myanmar (MMR), Singapore (SGP), the Philippines (PHL), Thailand (THA), and Vietnam (VNM).

3.3. Potential hydrogen supply

Figure 4 compares renewable energy potential with total power generation in 2050. RE P1 represents renewable energy potential as analyzed in ERIA (2022), and RE P2 is based on IRENA & ACE (2022). Both analyses include solar PV, onshore wind power, offshore wind power, biomass, hydropower, and geothermal power. Even under the assumption that renewable energy will cover both total power generation in 2050 as projected in ERIA (2021) and the additional power generation needed to accommodate increased electrification demand driven by further electrification in 2050 and beyond, the renewable energy potential in most ASEAN countries exceeds total power generation. Therefore, surplus renewable energy is available for use in hydrogen production.

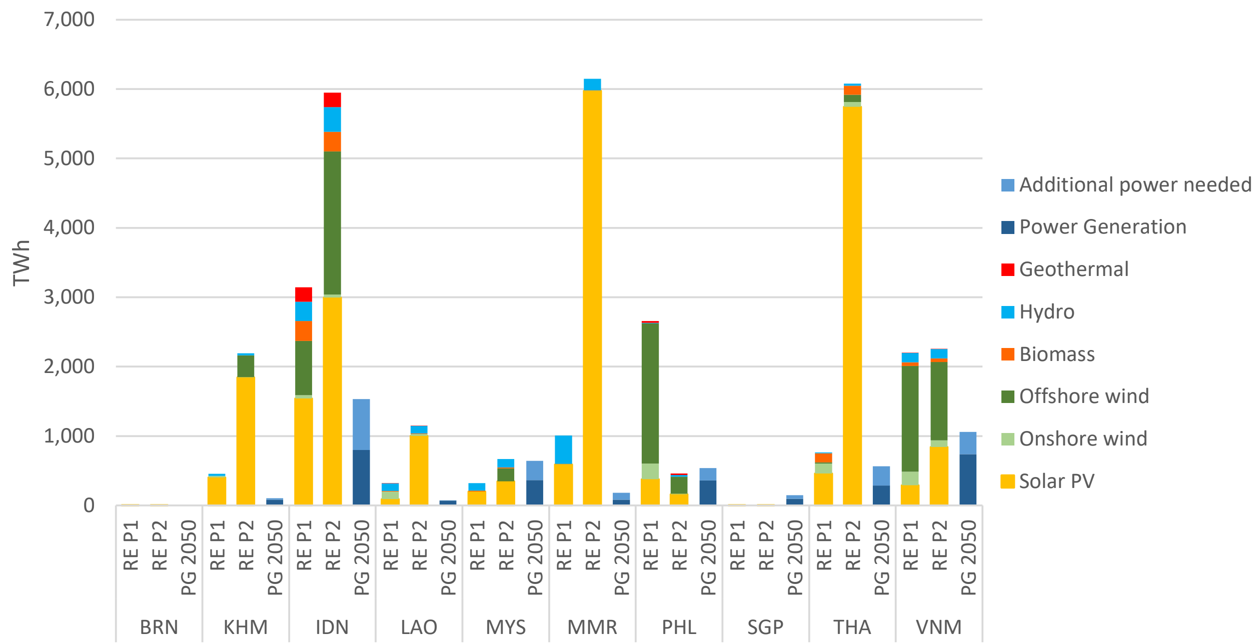

FIGURE 4. RENEWABLE ENERGY POTENTIAL FOR HYDROGEN PRODUCTION

Notes:

1) The country codes used are as follows: Brunei Darussalam (BRN); Cambodia (KHM), Indonesia (IDN); Lao DPR (LAO); Malaysia (MYS); Myanmar (MMR); Singapore (SGP); Thailand (THA); and Vietnam (VNM)

2) "Power generation" represents power generation in 2050, based on APS in ERIA (2021). "Additional power needed" represents the power generation needed to accommodate the increased demand driven by further electrification in 2050 and beyond, calculated by the authors based on an estimation of how much remaining fossil fuel use in 2050 can be electrified.

3) Solar PV will account for a significant share of renewable energy in the ASEAN region. Since solar power is available only during the day, this suggests a low capacity factor for electrolyzers, and thus high hydrogen production costs. However, if electrolyzer costs become sufficiently low, then this should not be a critical issue.

Across the entire ASEAN region, total power generation is projected to be 2,900 TWh in 2050 (ERIA, 2021). Additional electric power generation to accommodate electrification demand in 2050 and beyond will amount to 2,000TWh, calculated by the authors based on an estimation of how much remaining fossil fuel use in 2050 can be electrified. Together total electric power demand will be 4,900 TWh. Given that ASEAN-wide renewable energy potential ranges between 11,000 (RE P1) ~ 25,000 (RE P2) TWh, 6,000 ~ 20,000 TWh of renewable energy can be used for hydrogen production.

The potential for hydrogen production is especially large in Cambodia, Indonesia, Laos PDR, Myanmar, Thailand, and Vietnam.

Chapter 4. Conclusions

4.1. Meeting regional demand

Based on the potential hydrogen supply (optimistic case) and demand concluded in Chapter 3, the authors analyzed whether potential hydrogen supply would suffice potential demand in 2050 (Figure 5). In all countries except Malaysia, as well as Brunei Darussalam and Singapore where both supply and demand will be limited, potential supply exceeded demand. Myanmar and Thailand marked an outstanding amount of potential surplus supply. In total, the ASEAN region bears the potential to supply three times the potential hydrogen demand in 2050.

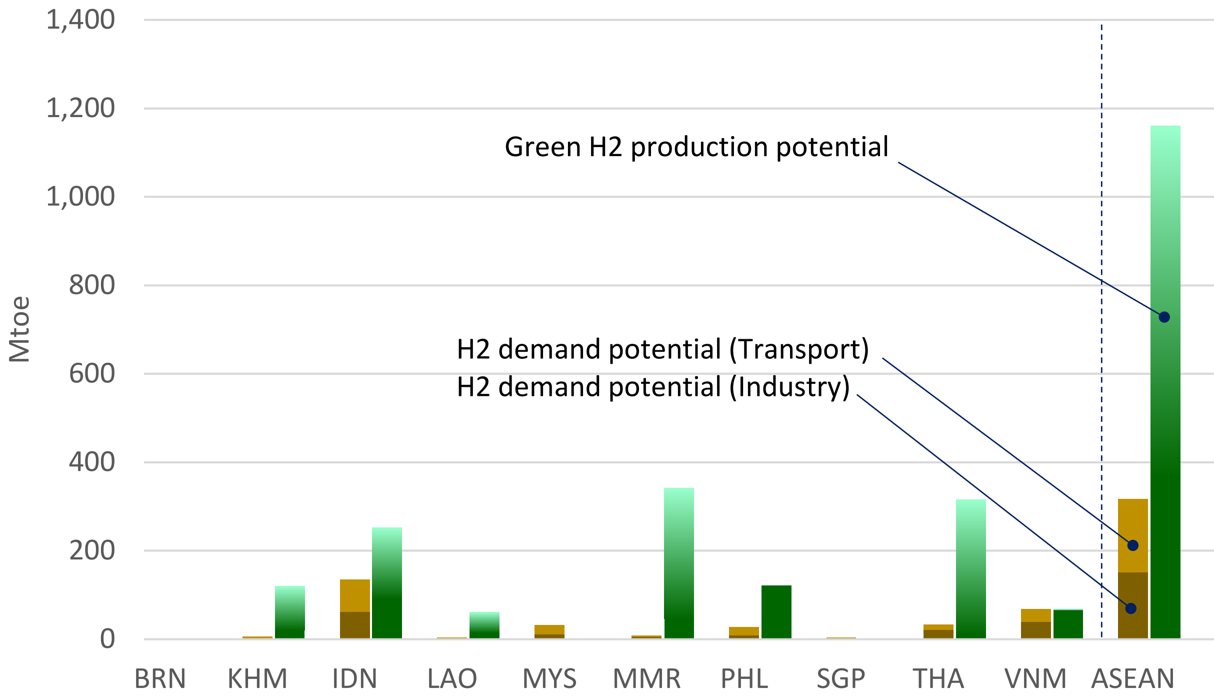

FIGURE 5. COMPARISON OF POTENTIAL GREEN HYDROGEN SUPPLY & DEMAND (2050)

Note:

The country codes used are as follows: Brunei Darussalam (BRN), Cambodia (KHM), Indonesia (IDN), Lao DPR (LAO), Malaysia (MYS), Myanmar (MMR), the Philippines (PHL), Singapore (SGP), Thailand (THA), and Vietnam (VNM)

Since there are many different approaches to defining renewable energy potential, depending on which constraints to developing their full physical potential are considered, the sufficiency of potential green hydrogen supply to meet regional demand in 2050 was analyzed for a range of cases. Figure

6 presents the amount of surplus hydrogen supply ranging from the most pessimistic to the most optimistic potential supply studied.

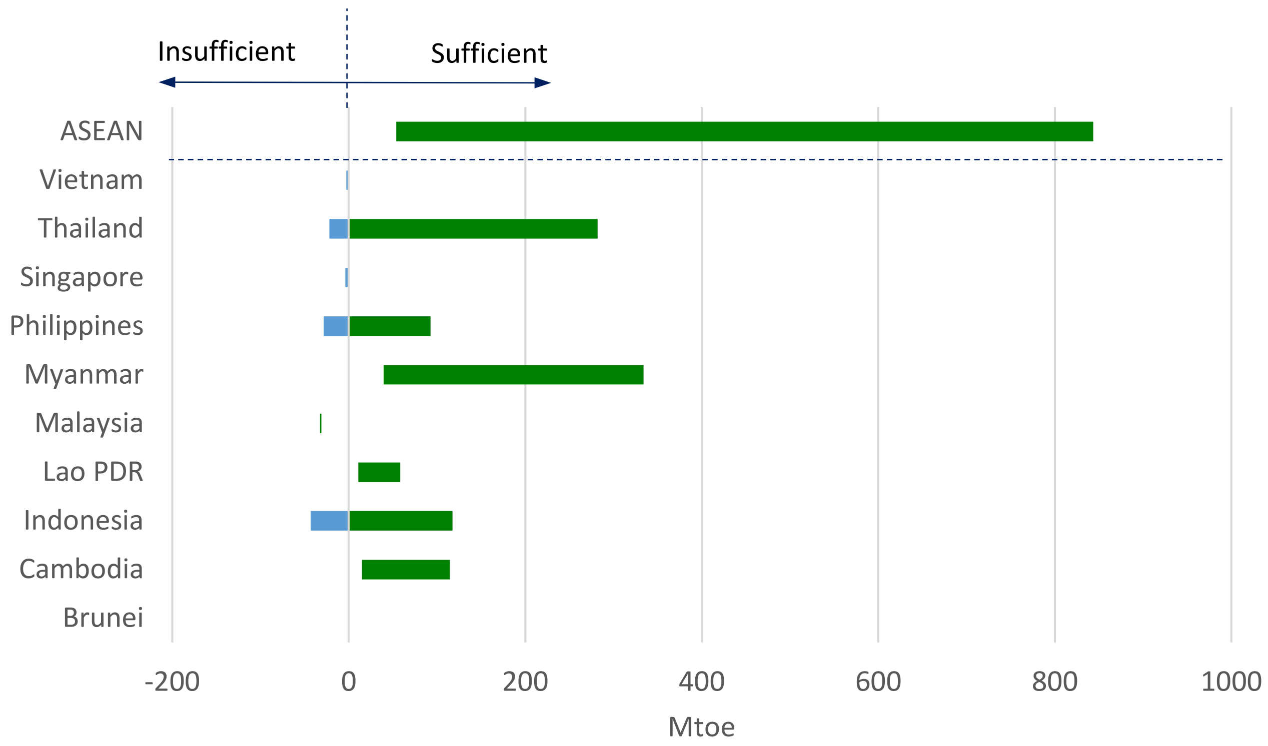

FIGURE 6. SUFFICIENCY OF POTENTIAL GREEN HYDROGEN SUPPLY (2050)

Note:

The country codes used are as follows: Brunei Darussalam (BRN); Cambodia (KHM), Indonesia (IDN); Lao DPR (LAO); Malaysia (MYS); Myanmar (MMR); Singapore (SGP); Thailand (THA); and Vietnam (VNM)

Myanmar, Lao PDR, and Cambodia will have sufficient hydrogen supply to cover domestic demand. Other than Brunei Darussalam, Malaysia, Singapore, and Vietnam, where demand will exceed supply in all cases, Thailand, the Philippines, and Indonesia may have a shortage of domestic supply when the physical potential is not fully harnessed.

The entire ASEAN region will have a surplus supply of green hydrogen, ranging from 54~843 Mtoe[7]. Therefore, even in the most pessimistic case (54 Mtoe surplus green hydrogen), there is an ample potential supply of green hydrogen across the entire ASEAN region to cover regional hydrogen

[7] It should be noted that this study does not consider economic growth beyond 2050. When energy consumption increases with economic growth, the amount of surplus renewable energy available for hydrogen production will decrease.

demand. Therefore, the intra-regional trade of green hydrogen could offer a solution to the region-wide decarbonization of hard-to-abate industries using local resources.

Green hydrogen production may change the geopolitics of the ASEAN region to some extent. Low-income economies, such as Myanmar, Lao PDR, and Cambodia, will have the opportunity to become the region's energy supplier. However, as seen in Chapter 2, most ASEAN countries have yet to develop national hydrogen strategies, or even include hydrogen in their national energy plans. Furthermore, there are various challenges to developing the full renewable energy potential of the region. These include the lack of financial support and channels, lack of experience and regulatory frameworks, insufficient coordination among government agencies, and limited infrastructure, such as grid enhancement needs for massive renewable integration. The power development plans and renewable power targets laid out by each country also fall substantially short of their renewable energy potential (Table 4). Therefore, policy measures will need to be in place to harness their full potential.

TABLE 2. COMPARISON OF RENEWABLE TARGETS AND POTENTIAL (GW)

	Renewable power target	Potential (RE P1)
IDN	552 GW (2060) (proposed National Grand Energy Strategy)	1,884 GW
MYS	18 GW (2035) (MyRER)	225 GW
PHL	61 GW (2040) (NREP 2020-2040)	963 GW
THA	19 GW (2037) (AEDP 2018)	378 GW

Source: compiled by authors based on various sources, as indicated

Notes:

1) The country codes used are as follows: Indonesia (IDN), Malaysia (MYS), Philippines (PHL), and Thailand (THA)

2) Renewable power capacity targets are compared with renewable energy potential of countries with large potential in the most pessimistic scenario. Renewable power target for Indonesia is based on the proposed National Grand Energy Strategy[8]; for Malaysia, the Malaysia Renewable Energy Roadmap; for the Philippines, National Renewable Energy Plan 2020-2040; and for Thailand, the Alternative Energy

[8] MEMR (February 4, 2022, press release) "Indonesia to Introduce Grand Energy Strategy during G20 2022" https://www.esdm.go.id/en/media-center/news-archives/pemerintah-kenalkan-gsen-pada-presidensi-g20-indonesia

Development Plan 2018. Vietnam has not been included as PDP8 has yet to be released as of January 31, 2023.

4.2. Exporting green hydrogen outside the ASEAN region

In the entire ASEAN region, there will be 54~843 Mtoe of green hydrogen, which is equivalent to around 10～300 Mt-H2. This implies that the region is a potential green hydrogen exporter.

Japan aims to introduce 3 million tonnes of hydrogen in 2030 and 20 million tonnes in 2050.The ASEAN region bears the potential to become a major supplier of green hydrogen for Japan. The proximity of the region to Japan will be an advantage. Furthermore, green hydrogen imports from the ASEAN region will contribute to diversifying its energy imports, and thus serve Japan’s energy security.

Another consideration to be made is Singapore’s global importance as a bunkering hub. Singapore is one of the world’s largest bunkering hubs, supplying almost 50 million tonnes of marine bunker fuel to vessels in 2021[9]. Amid increasing calls for low-carbon vessel fuels led by the International Maritime Organization (IMO)[10], green hydrogen will play an important role in decarbonizing marine fuels. The Maritime and Port Authority of Singapore seeks to offer various low and zero-carbon fuel solutions to support the bunkering needs of the global shipping industry (MPA, 2022). The MPA expects hydrogen and its carriers (including ammonia and e-methanol) as well as bio-LNG to potentially play important roles in the decarbonization of international shipping in the medium to long term. If the surplus supply of green hydrogen (around 50～850 Mtoe) were to be converted to e-fuel, the region would be able to supply around 40～600 Mtoe[11] of e-fuel. Hence, while in the most pessimistic case, the region will not be able to produce enough e-fuel to fully cover Singapore’s bunker sales, a reasonable amount of regionally produced e-fuel can be collected in Singapore from across the ASEAN region. This can potentially offer large business opportunities for the ASEAN region.

9 Maritime and Port Authority of Singapore (n.d) Bunkering Statistics https://www.mpa.gov.sg/port-marine-ops/marine-services/bunkering/bunkering-statistics

10 The IMO aims to reduce carbon intensity (emissions per transport work) by at least 40% by 2030, pursuing efforts towards 70% by 2050.

11 A conversion efficiency of 70% is assumed.

Chapter 5. Recommendations

5.1. Building an intra-regional green hydrogen supply chain

The ASEAN region possesses significant renewable energy potential substantially exceeding the projected power generation in 2050. By harnessing this surplus renewable energy to produce hydrogen, hard-to-abate industries and transport in the region can be decarbonized.

However, while some ASEAN member countries have sufficient potential to cover domestic demand, other countries will see a shortage in hydrogen supply. In addition, areas with high hydrogen demand are not always located close to potential production hubs; and therefore, new international supply chains and networks will need to be built. By establishing an intra-regional supply chain and distribution network, all ASEAN countries will gain access to green hydrogen.

Green hydrogen produced in the ASEAN region may not always be the cost-competitive option compared to hydrogen produced in other regions of the world. However, while studies including IEEJ (2021) have pointed out that the distance from the origin of the hydrogen to its destination does not greatly affect the cost of hydrogen, limiting hydrogen imports from outside the ASEAN region will contribute to enhancing regional energy security. Regional production will also enable hydrogen-driven economic growth.

Yet, building an intra-regional green hydrogen supply chain will entail many challenges. First, considerations will need to be made at the regional level regarding the preferred hydrogen carrier and mode of distribution. Many studies are currently being conducted globally on different hydrogen carriers, including liquid hydrogen, methylcyclohexane (MCH), ammonia, and e-methane. The advantages and disadvantages of each carrier will need to be carefully considered in light of various factors, including cost, infrastructure availability, and end-use applications.

Another important consideration would be whether it would be more cost-effective to produce hydrogen close to the renewable energy source for shipping via pipeline, lorry or vessel, or to transmit renewable power through international transmission lines for hydrogen production at a so-called hydrogen hub, ideally close to a port. IRENA (2020a) suggests that suitable transmission lines are rare and costly; and therefore, hydrogen carriers could enable the trade of hydrogen as molecules or commodities. This would also contribute to developing the green hydrogen market in the ASEAN region.

It is important that these decisions are made in consensus across the region so that the infrastructure, including shipping and receiving ports, as well as storage facilities, match the preferred hydrogen carrier. Existing local laws and regulations or the absence of such instruments may become barriers to the development of infrastructure or even the handling of hydrogen and its derivatives, as they are currently mainly used in the refining, fertilizer, and petrochemical industries. As the green hydrogen market develops, a regional certification scheme for hydrogen that is consistent across borders will be essential in ensuring that there are no mismatches between the exporter and importer.

Many Japanese companies are frontrunners in exploring the development of a commercial hydrogen supply chain with different carriers. Having succeeded in the international sea shipping of hydrogen to Japan[12], they are currently scaling up their technologies. With more than eighty years' experience in handling hydrogen, Japan is home to an established domestic liquid hydrogen distribution network. Japan's experience with relevant infrastructure, transportation and storage technologies, laws and regulation, and safety standards can help develop ASEAN's regional hydrogen market.

5.2. Further promoting renewable energy deployment

For green hydrogen to be a realistic and optimal solution for decarbonizing the economy, the renewable power used in its production should be available in surplus to that needed for more efficient uses. Renewable power should primarily be fully harnessed to decarbonize sectors whose carbon footprint can be lowered by using it directly. Therefore, investment should first be targeted at developing renewable energy to secure the surplus resources that will be needed to produce green hydrogen.

To support this, it is essential that polices are put in place for the massive deployment of renewable energy in each country. This will help lower renewable power generation costs, which remain and in turn bring down green hydrogen production costs, which is most affected by power generation costs (IEEJ, 2021).

One of the factors that has hindered the development of renewable energy in the ASEAN region is fossil fuel subsidies. Many ASEAN countries have provided subsidies to make fossil fuels affordable for the general public[13]. By lowering the cost of fossil fuels relative to renewable sources, such

[12] The CO2-free Hydrogen Energy Supply-chainTechnology Research Association (HySTRA, https://www.hystra.or.jp/en/) successfully demonstrated that hydrogen can be produced using Latrobe Valley coal and a mix of biomass and transported to Japan as liquefied hydrogen. In 2020, the Advanced Hydrogen Energy Chain Association for Technology Development (AHEAD) completed an international hydrogen supply chain demonstration, bringing hydrogen from Brunei to Japan using the Organic Chemical Hydride method, which involves fixing hydrogen to toluene to convert it to methylcyclohexane (MCH) as a Liquid Organic Hydrogen Carrier (LOHC).

[13] In 2021, Brunei, Indonesia, Malaysia, Thailand, and Vietnam had fossil fuel subsidies in place. The total subsidy as share of GDP was 1.5%, 2.7%, 1.0%, 0.6%, and 2.3%, respectively. Indonesia, Malaysia, and Thailand have abolished transport oil subsidies in their fossil fuel subsidy reforms. (IEA, 2022a)

subsidies can create an artificial cost advantage (Bridles & Lucy, 2014). The public funds allocated to fossil fuels should be invested in renewable energy. Later when green hydrogen is deployed, policies can be put in place to incentivize the use of vehicles powered by green hydrogen-derived fuels.

Another challenge is the need to upgrade the power grid in ASEAN countries to enable the integration of increased amounts of variable renewable energy, such as solar PV and wind power.

Despite ongoing discussions about co-firing ammonia in existing coal-fired power plants, the authors did not consider this technology in the current analysis. This is because the process of producing hydrogen by electrolysis and converting it to ammonia for use in coal-fired thermal power plants will reduce the total energy efficiency to 20%.

It should be noted that the authors have not conducted an economic analysis of producing green hydrogen in the ASEAN region. In 2050, the levelized cost of hydrogen in the region will not be as competitive as that of other regions and countries (IRENA, 2022b)[14]. Therefore, importing green hydrogen from outside the region may prove to be more cost-effective. However, regional production of hydrogen for regional use of hydrogen will serve its energy security. Japan can play an important role in building and expanding the regional hydrogen market and thus bringing costs down through cooperation with ASEAN countries on hydrogen-related technology development.

5.3. Japan's role in promoting green hydrogen development in the ASEAN region

Both the public and private sectors in Japan can contribute greatly to the development of renewable energy in the ASEAN region. Since the renewable energy market is yet to be fully developed in some countries, players may be able to enjoy first-mover advantage in establishing the business environment for renewable energy, and in turn for hydrogen. Overseas hydrogen-related technology development led by Japan to date have tended to focus on hydrogen carriers and other downstream components of the international hydrogen supply chain. Increased investment and government support in the earlier phases of the supply chain will not only help accelerate the decarbonization of the electric power sector in the ASEAN region but also give Japanese actors increased access to renewable power for green hydrogen production. The proximity of the ASEAN region to Japan, compared to other potential exporters is an advantage with a view to enhancing energy security.

[14] The levelized cost of hydrogen (LCOH) derived from supply-demand analysis of the ASEAN region is estimated to be USD 2.0 based on the estimated hydrogen demand for 2050. This cost level is only competitive against Ukraine, Japan, and the Republic of Korea among the regions and countries evaluated.

2023 marks the “50th Year of ASEAN-Japan Friendship and Cooperation.” Over the years, Japan has built many cooperation frameworks in place for supporting ASEAN countries’ energy transition. Under these frameworks, Japan can also support the designing of aggressive but feasible decarbonization policies with consideration of region-specific circumstances and needs. Such support could include not only technological and financial support, but also in-depth studies to reveal local challenges and solutions, support in formulating master plans based on such studies, and the implementation of stakeholder dialogue.

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Appendix 1

Climate goals in the ASEAN region

The carbon neutrality goal, greenhouse gas reduction targets, and coal phase-out policy set out by each ASEAN member economy are compiled in Table A.

TABLE A. CLIMATE GOALS IN THE ASEAN REGION

Country[1)]	Carbon neutrality goal	2030 GHG reduction target (NDC)				Coal phase-out policy
		Reduction target type	Unconditional target	Conditional[2)] target	Baseline year	
BRN	2050	Relative emissions	20%	-	BAU	Yes
KHM	2050	Relative emissions	41.7%	-	BAU	Yes[4)]
IDN	2060	Relative emissions	29%	41%	BAU	Yes[4)]
LAO	2060	Relative emissions	60%	-	Baseline	No
MYS	2050	Carbon intensity	45%	-	2005	Yes[4)]
MMR	2050	Other	Avoidance of 245 $MtCO_2$	-		No
PHL	-	Relative emissions	2.71%	75%	BAU	Yes[4)]
SGP	2050	Carbon intensity	36%[4)]	-	2005	Yes
THA	2050[2)]	Relative emissions	20%	25%	BAU	No
VNM	2050	Relative emissions	9%	27%	BAU	Yes

Source: compiled by authors based on NDCs and other sources

Notes:

1) The country codes used are as follows: Brunei Darussalam (BRN), Cambodia (KHM), Indonesia (IDN), Lao DPR (LAO), Malaysia (MYS), Myanmar (MMR), the Philippines (PHL), Singapore (SGP), Thailand (THA), and Vietnam (VNM)

2) Conditional targets are dependent on the availability of international support for finance, technology transfer and development, and/or capacity building.

3) Thailand aims to achieve carbon neutrality by 2050 and net zero carbon GHG emissions by 2065.

4) No new projects will be approved.

5) Singapore aims to peak emissions in 2030, which will lead to 36% reductions relative to 2005 in 2030.

APPENDIX 2

Renewable energy targets in the ASEAN region

Brunei Darussalam: Under Brunei Vision 2035[15], Brunei aimed to increase the deployment of renewable energy up to 10% in 2035. This target was updated in its National Climate Change Policy[16], which aims to have a 30% share of renewables, comprising mostly solar PV, by 2035.

Cambodia: The Cambodia Basic Energy Plan (BEP)[17] recommends a power generation mix of coal (35%), hydropower (55%), and other renewable energy (10%) for 2030. This was updated in its Long-Term Strategy for Carbon Neutrality[18] published in December 2021, in which it pledged to increase solar PV, hydro, biomass, and other renewables to 35% of the power generation mix by 2050. Solar PV will account for 12%.

Indonesia: Under its National Energy Policy[19] enacted in 2014**,** Indonesia seeks to source 23% of its energy mix with renewable energy by 2025 and 31% by 2050. The government has also announced that it is formulating a National Grand Energy Strategy (GSEN) that proposes to have new and renewable energy cover 100% power generation in 2060, when total power generation capacity will be 587 GW, comprising 361 GW solar PV, 83 GW hydropower, 39 GW wind power, 35 GW nuclear power, 37 GW bioenergy, 18 GW geothermal power, and 13.4 GW ocean currents power [20].

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[15] Wansan Brunei 2035, https://www.wawasanbrunei.gov.bn/sitepages/Home.aspx

[16] Brunei Climate Change Secretariat (2020) *Brunei Darussalam National Climate Change Policy*, http://www.mod.gov.bn/Shared%20Documents/BCCS/Brunei%20National%20Climate%20Change%20Policy.pdf

[17] General Department of Energy (GDE), Cambodia (2019). *Cambodia Basic Energy Plan,* https://policy.asiapacificenergy.org/sites/default/files/Cambodia%20Basic%20Energy%20Plan.pdf

[18] Kingdom of Cambodia (2021) *Long-Term Strategy for Carbon Neutrality* (LTS4CN), https://ncsd.moe.gov.kh/resources/document/cambodia-LTS4CN-En

[19] Government Regulation of the Republic of Indonesia Number 79 of 2014 on National Energy Policy, *Long-Term Strategy* for Carbon Neutrality (LTS4CN), https://ncsd.moe.gov.kh/resources/document/cambodia-LTS4CN-En

[20] MEMR (February 4, 2022 press release) "Indonesia to Introduce Grand Energy Strategy during G20 2022" https://www.esdm.go.id/en/media-center/news-archives/pemerintah-kenalkan-gsen-pada-presidensi-g20-indonesia

Lao PDR: Lao PDR aims to increase the share of renewable energies to 30% of total energy consumption in 2025 under the Renewable Energy Development Strategy of Lao PDR[21] published in 2011.

Malaysia: In 2021, the Ministry of Energy and Natural Resources (KeTSA) set a target to reach a 31% share of renewable energy in the national installed capacity mix by 2025[22]. In the Malaysia Renewable Energy Roadmap[23], the New Capacity Target scenario achieves the abovementioned national target and aims to reach a 40% share in 2035. This target supports Malaysia's global climate commitment to reduce its economy-wide carbon intensity (against GDP) by 45% in 2030 relative to 2005 levels.

Myanmar: The National Electrification Program (NEP)[24] envisions 100% nationwide electricity access by the year 2030. According to the U.S. International Trade Administration, the Ministry of Electricity and Energy (MOEE) drafted a renewable energy law with the goal of generating 8% of the country's electricity through renewable sources by 2021, raising its share to 12% by 2025[25]. In April 2022, the Ministry of Information (MOI) and the Ministry of Investment and Foreign Economic Relations (MIFER) of Myanmar issued a joint press release stating that the government is planning to accelerate development of renewable energy development while seeking to increase foreign investment[26].

Philippines: The Philippines' National Renewable Energy Program (NREP) 2020-2040[27] sets a target of reaching a 35% share of renewable energy in the power generation mix by 2030 and a 50%

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[21] Lao People's Democratic Republic (2011) *Renewable Energy Development Strategy in Lao PDR* https://data.laos.opendevelopmentmekong.net/en/dataset/renewable-energy-development-strategy-in-lao-pdr

[22] Department of Energy, Malaysia (2021). *Twelfth Malaysia Plan 2021-2025 (RMK12)*, https://rmke12.epu.gov.my/en

[23] Sustainable Energy Development Authority, Malaysia (2021), *Malaysia Renewable Energy Roadmap: Pathway towards Low Carbon Energy System*, https://www.seda.gov.my/reportal/wp-content/uploads/2021/12/MyRER_webVer-1.pdf

[24] World Bank (n.d.) "National Electrification Program," https://projects.worldbank.org/en/projects-operations/project-detail/P152936

[25] International Trade Administration, (July 28, 2022) "Burma – Country Commercial Guide" https://www.trade.gov/country-commercial-guides/burma-energy

[26] Bloomberg (April 22, 2022) "Myanmar Govt to Accelerate Energy Projects Amid Power Shortages", https://www.bloomberg.com/press-releases/2022-04-21/myanmar-govt-to-accelerate-energy-projects-amid-power-shortages-l29d0bp8

[27] Department of Energy, Philippines (2022). *National Renewable Energy Program 2020-2040*, https://www.doe.gov.ph/sites/default/files/pdf/renewable_energy/nrep_2020-2040_0.pdf

share by 2040. To meet this target, the Philippines will need to install another 102 GW renewable electricity capacity by 2040 including 27 GW solar PV, 17 GW wind power, 6GW hydropower, 2.5 GW geothermal, and 364 MW biomass.

Singapore: In February 2022, the Minister of Finance announced at Budget 2022 that Singapore will aim to achieve net zero emissions by or around mid-century by progressively raising its carbon tax from 2024[28]. In the Singapore Green Plan 2030[29] launched in February 2021, Singapore announced its ambition to increase solar energy deployment by five-fold to at least 2 GWp, which would cover around 3% of projected electricity demand in 2030.

Thailand: Thailand's Alternative Energy Development Plan 2018-2027[30] seeks to increase the proportion of renewable energy in Thailand to 30% (including imported hydropower) of total energy consumption by 2037.

Vietnam: In 2015, the government announced the national development strategy for renewable energy, aiming for renewable energy to account for around 32% of total primary supply and electricity generation by 2030 and 43% by 2050[31]. Targets are to be updated in the Power Development Plan VIII (PDP8), which is still under discussion.

TABLE B. RENEWABLE ENERGY TARGETS IN SELECTED ASEAN COUNTRIES

Country[1)]	Current share (2020)	Target share (Target year)	Description
BRN	0%	30% (2035)	Brunei Darussalam National Climate Policy (2020)[32]
KHM	28%	35% (2050)	Long-term Strategy for Carbon Neutrality (2021)[33]
IDN	26%	31% (2050)	National Energy Policy (2014)[34]

[28] National Climate Change Secretariat, (February 18, 2022) "Singapore Will Raise Climate Ambition to Achieve Net Zero Emissions by or Around Mid Century, and Revises Carbon Tax Levels from 2024" https://www.nccs.gov.sg/media/press-release/singapore-will-raise-climate-ambition/

[29] "Singapore Green Plan 2030" https://www.greenplan.gov.sg

[30] Ministry of Energy, Thailand (2020). *Alternative Energy Development Plan 2018 (AEDP 2018)*, https://policy.asiapacificenergy.org/sites/default/files/Alternative%20Energy%20Development%20Plan%202018-2037%20%28AEDP%202018%29%28TH%29.pdf

[31] Decision No. 2068/QD-TTg, 2015, https://lawnet.vn/en//vb/Decision-No-2068-QD-TTg-approving-the-development-strategy-of-renewable-energy-2030-2050-2015-48915.html

[32] Brunei Climate Change Secretariat (2020). *op. cit.*

[33] Kingdom of Cambodia (2021). *op. cit.*

[34] Government Regulation of the Republic of Indonesia Number 79 of 2014 on National Energy Policy, *op. cit.*

MYS	16%	40% (2035)	Malaysia Renewable Energy Roadmap (MyRER, 2021)[35]
PHL	21%	50% (2040)	National Renewable Energy Plan (NREP 2020-2040)[36]
THA	18%	30% (2027)	Alternative Energy Development Plan (AEDP 2018-2027)[37]
VNM	35%	43% (2050)	Development Strategy of Renewable Energy of Vietnam[38]; to be updated in PDP8.

Source: IEA (2022b) and various other sources, as indicated

Notes:

1) The country codes used are as follows: Brunei Darussalam (BRN), Cambodia (KHM), Indonesia (IDN), Malaysia (MYS), Thailand (THA), and Vietnam (VNM).

Renewable shares and targets are provided for the power generation mix in each country, with the exception of Indonesia and Thailand, for which the figures represent shares against the primary energy mix and total energy consumption, respectively.

[35] Sustainable Energy Development Authority, Malaysia (2021) *op. cit.*

[36] Department of Energy, Philippines (2022). *op. cit.*

[37] Ministry of Energy, Thailand (2020). *op. cit.*

[38] Decision No. 2068/QD-TTg, 2015, *op.cit.*

Appendix 3

Hydrogen Strategies in the ASEAN region

Brunei Darussalam: Brunei has yet to develop any national strategies related to hydrogen, but it has concluded Memoranda of Understandings (MOUs) with Asian countries such as Japan and Singapore on cooperation on building a hydrogen supply chain. Backed by funding from Japan's New Energy and Industrial Technology Development Organization (NEDO), the Advanced Hydrogen Energy Chain Association for Technology Development (AHEAD)[39] successfully completed trials of the world's first international shipment of Methylcyclohexane (MCH) and stable hydrogen extraction in 2020, when it delivered MCH produced in Brunei to Japan.

Indonesia: Indonesia's National Energy Plan (RUEN) lays out its new and renewable energy development plan until 2050, including a general action plan for hydrogen development, such as the preparation of regulatory frameworks, technological and manufacturing capacity development, and incentives provision. In the GSEN, the government estimates that green hydrogen generation will be introduced in 2031, gradually increasing to approximately 52 GW by 2060. That would be a 10% contribution to the power mix[40].

In 2022, the German-Indonesian Chamber of Industry and Commerce (EKONID) launched the Hydrogen Business Desk (HBD)[41] to provide information regarding the development of hydrogen, primarily green hydrogen in Indonesia. Indonesia also signed an MOC on Japan and Indonesia's energy cooperation for the realization of realistic energy transitions that utilize technologies and options including but not limited to hydrogen and fuel ammonia[42]. This has been followed up by an announcement of Japan`s intentions to mobilize resources and funding from Japanese public institutions together with local parties to support Indonesia's energy under the Asia Zero Emission Community (AZEC) cooperation framework[43]. Many corporate level agreements have also been signed on various hydrogen-related technologies.

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[39] Advanced Hydrogen Energy Chain Association for Technology Development (AHEAD) https://www.ahead.or.jp/en/

[40] MEMR (February 4, 2022, press release) *op. cit.*

[41] "Hydrogen Business Desk" https://www.hydrogen-indonesia.id/home

[42] METI, Japan (Jan. 13, 2022) "Memorandum of Cooperation Between the Ministry of Economy, Trade and Industry of Japan and the Ministry of Energy And mineral Resources of the Republic of Indonesia on the Realization of Energy Transitions" https://www.meti.go.jp/press/2021/01/20220113003/20220113003-1.pdf

[43] Ministry of Foreign Affairs, Japan (Nov. 14, 2022) "Joint Announcement on Asia Zero Emission Community (AZEC) Concept" https://www.mofa.go.jp/files/100420486.pdf

Malaysia: The Twelfth Malaysia Plan[44] encouraged the advancement of hydrogen technologies in the transport sector and mentioned the formulation of a Comprehensive National Energy Policy under which the prospect of future growth related to energy, particularly on the potential of new energy from clean and sustainable sources including hydrogen, will be explored. The National Energy Policy 2022-2040[45] includes initiatives to formulate a hydrogen roadmap, a national strategy, and relevant regulations. It also aims to establish an internationally competitive hydrogen energy hub in Sarawak in the long term (2031-2040).

A number of projects using hydropower to produce hydrogen have been jointly announced by local companies and collaborators from Japan[46], Korea, and France. Another cooperation arrangement will conduct a feasibility study on leveraging the abundant solar resources of Malaysia to produce and sell green ammonia[47].

Singapore: Singapore launched its National Hydrogen Strategy in October 2022[48]. While it does not lay out quantitative targets, Singapore seeks to develop hydrogen as a major decarbonization pathway to support its transition towards net zero by 2050. Singapore has concluded cooperation arrangements in the hydrogen field with governments, such as Japan, Australia, New Zealand, and Chile. Several corporate-level MOUs have also been concluded to explore hydrogen supply chains to bring low-carbon hydrogen to Singapore using different hydrogen carriers[49].

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[44] Department of Energy, Malaysia (2021). *op. cit.*

[45] Economic Planning Unit, Prime Minister's Department, Malaysia, (2022) National Energy Policy 2022-2040 (NEP2022-2040), https://www.epu.gov.my/sites/default/files/2022-09/National%20Energy%20Policy_2022_2040.pdf

[46] For example, ENEOS, Sumitomo Corporation and SEDC Energy Sdn Bhd are considering establishing a CO_2-free hydrogen supply chain using renewable power generated at hydroelectric power stations in Sarawak, Malaysia to produce hydrogen and converting it into methylcyclohexane (MCH). (https://www.eneos.co.jp/english/newsrelease/2020/pdf/20201023_01.pdf)

[47] IHI (Dec. 15, 2022 press release) "IHI and Gentari sign MoU to explore Green Ammonia Production and Sales in Malaysia" https://www.ihi.co.jp/en/all_news/2022/resources_energy_environment/1198122_3488.html

[48] Ministry of Trade and Industry, Singapore (2022). *Singapore's National Hydrogen Strategy*, https://www.mti.gov.sg/Industries/Hydrogen

[49] For example, Sembcorp Industries, Chiyoda Corporation, and Mitsubishi Corporation signed an MOU in 2021 to explore a hydrogen supply chain using MCH (https://www.sembcorp.com/en/media/media-releases/energy/2021/october/sembcorp-industries-chiyoda-corporation-and-mitsubishi-corporation-sign-mou-to-explore-supply-chain-commercialisation-of-decarbonised-hydrogen-into-singapore/); Itochu, EDF, and Tuas Power signed an MOU on developing a green ammonia supply chain and exploring different applications,

Thailand: The Alternative Energy Development Plan 2015-2037 (AEDP2015)[50] included hydrogen as part of the "Alternative Fuels" category with a target goal of 10 Ktoe for transportation by 2036. However, AEDP2018 has excluded the category.

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including for power generation and as a shipping fuel (https://www.itochu.co.jp/en/news/press/2022/221026.html).

[50] Ministry of Energy, Thailand (2015). *Alternative Energy Development Plan 2015 (AEDP 2015),* https://www.eppo.go.th/images/POLICY/ENG/AEDP2015ENG.pdf