Chapter 7

Conclusions, Policy Recommendations, and Way Forward

Alloysius Joko Purwanto
Ridwan Dewayanto Rusli

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This chapter provides conclusions, recommendations, and the next steps of research that can be done in the future to explore more insights based on this study's findings.

1. Conclusions

Departing from the facts that current hydrogen use in ASEAN countries is entirely absorbed in the industry sector, and that this hydrogen is almost fully produced by conventional steam methane reforming pathway with high carbon intensity, this study analyses the historical use of hydrogen in the industry sector, i.e. oil refining, methanol, ammonia, and iron and steel industries in ASEAN countries and makes projections to the horizon 2050 in several scenarios.

Several conclusions can be elaborated as follows:

- **Between 2015 and 2021, hydrogen demand increased in ASEAN countries with two industry sectors, i.e. ammonia and oil refining being its drivers.**

Hydrogen demand in industry sectors in ASEAN grew from around 3.270 million tons per annum (MTPA) in 2015 to around 3.745 MTPA in 2021. The most important share of hydrogen demand in ASEAN came from the ammonia industry, which increased steadily from around 46% in 2015 to 49% in 2021. Oil refining's share, the second biggest, dropped from around 37% in 2015 to around 32% in 2021. By 2021, hydrogen demand from the methanol industry share reached almost 15% in 2021, increasing from around 11% in 2015. The iron and steel industry on the other hand, saw its small hydrogen demand share drop from 2.2% in 2015 to 0.7% in 2021. The chemical industry's hydrogen demand share remained below 4% during the 2015–2021 period.

During the 2015–2021 period, the methanol industry demand for hydrogen grew the fastest, with a compound average growth rate (CAGR) of 7.2%, followed by the ammonia industry (3.4% CAGR). The oil refining industry hydrogen demand remained stable as its CAGR approached 0%, whilst the iron and steel industry saw a strong drop in hydrogen demand, i.e. from 70,700 tons per annum (PA) in 2015 to 25,200 TPA in 2021.

Most of the hydrogen demand in the industry sector in ASEAN was supplied by captive onsite production in each sector. In 2015, around 88% of the demand was met by captive hydrogen supply and by 2021 this percentage dropped slightly to 86.5%.

- **Future situations, from now to the horizon 2050 the demand and supply of hydrogen in ASEAN countries can be represented in scenarios that differ in their climate ambitions.**

Four scenarios are defined in the study to describe future scenarios: ERIA–Frozen, ERIA–STEPS, ERIA–Likely, and ERIA–APS.

The ERIA–Frozen scenario relates to a future situation where the trend as shown in the demand and supply of hydrogen by the historical trend of the 2015–2021 period will continue as it is. It assumes that ASEAN countries only maintain a business-as-usual approach without any national CO_2 or renewable energy (RE) or energy efficiency (EE) targets to meet. Here hydrogen demand and supply in the future would grow at the same average rate of the 2015–2021 period, and supply including announced capacity expansion will be able to meet demand using the same supply structure as it is during the 2015–2021 period.

The ERIA–STEPS is inspired by the Stated Policies Scenario (STEPS) described in IEA (2022a) and IEA (2022b). Basically, it retains current and the latest ASEAN Member States' (AMS) policies, including those related to the Intended Nationally Determined Contribution (INDC). The scenario has no particular outcome to achieve, meaning that there is no additional policy implementation apart from the implementation of those based on INDC, e.g. shifting to a certain percentage of renewable use in power generation at a certain point in time, or increasing energy efficient in several final sectors. The scenario explores where the energy system might go without additional policy implementation and takes a granular, sector-by-sector look at existing policies and measures and those under development without any guarantee that the intended CO_2 emissions reduction will be achieved.

The ERIA–APS is based on the Announced Pledges Scenario (APS) of IEA (2022b) that assumes that all aspirational targets announced by governments are met on time and in full, including their long-term net-zero and energy access goals. Government targets in the scenario are assumed to be achieved on time and in full. The scenario includes all the climate commitments made by governments around the world including INDC as well as longer-term NDC targets and assumes that they will be met in full and on time and fills the 'implementation gap' that needs to be closed by countries from the STEPS to achieve their announced decarbonisation targets. The scenario includes net-zero pledges as announced by countries, in this case ASEAN countries' pledges.

The ERIA–Likely scenario represents the most likely future situation in the supply and demand of hydrogen in the four industrial sectors in ASEAN from the present time to the horizon 2050. It is inspired by the forecast of hydrogen demand in DNV (2022). In this scenario, hydrogen produced globally to be used as feedstock would grow from around 90 million tons (MT) in 2020 to reach 195 MT in 2050, whilst the Southeast Asian region's demand would reach 4.1% of the total global hydrogen and its derivatives demand by 2050. ERIA's 2050 estimate of ASEAN's hydrogen demand share is thus higher than DNV's (2022) estimated 3.9% share, presumably due to faster electrification and decarbonisation, and thus a reduction in hydrogen demand from refineries in the industrialised Western economies.

Grid-based electrolysis costs will decrease significantly towards 2050 averaging around US$1.5 per kg. Globally, green hydrogen will reach cost parity with blue hydrogen within the next decade. The scenario also assumes that green hydrogen will increasingly be the cheapest form of production in most regions and that hydrogen demand for ammonia and methanol production will be diversified, not only as feedstock for conventional production for industrial use (e.g. fertiliser and chemicals), but also as energy carriers and e-fuel that will show their penetration in the late 2030s or during the 2040–2050 decade.

The main inputs to obtain future estimates of hydrogen demand and supply in each country and industry sectors are socio-demographic trends, external policy measures that might include more stringent climate change and environmental requirements, and the effects of those policy measures on the technological costs. Based on those inputs spread along the modelled period to the horizon 2050, the development of demand and supply for hydrogen as feedstock are estimated.

- **The most ambitious scenario will require the highest quantities of hydrogen compared to others and the hydrogen must be low-carbon or green hydrogen. Less climate-ambitious scenarios might show high demand for hydrogen, albeit with carbon intensities higher than in the more ambitious scenarios.**

The ERIA–APS appears to be the scenario where total hydrogen demand for the industry sector in ASEAN will increase the fastest during the simulated 2020–2050 period. In this scenario where net-zero emissions targets are assumed to be reached by the AMS by the mid 21st century, the hydrogen demand in the industrial sector in ASEAN would increase from around 3.7 MTPA in 2020 to 11.7 MTPA in 2050. The use of hydrogen as energy carriers and fuels as feedstock to produce e-methanol, ammonia fuels, and e-kerosene is the main driving factor of this fast growth and the used hydrogen in this scenario must be low-carbon (intensity) hydrogen, as only the use of low-carbon hydrogen will lead to net-zero emissions.

Total hydrogen demand in 2050 in the ERIA–Frozen and ERIA–Likely scenarios are found to reach almost similar levels, but the composition and sequence of hydrogen use in the two scenarios differ. In other words, carbon emissions in the ERIA–Likely scenario should go down much more significantly than in the ERIA–Frozen scenario even when the total volumes of hydrogen demand are similar.

In the 2020–2030 period, the CAGR of the total hydrogen demand in the ERIA-Likely scenario is weakest of all scenarios as traditional hydrogen demand declines especially in oil refining due to mobility electrification, whilst at the same time ammonia-energy and e-fuels technology have not been initiated yet. By contrast, ERIA–Frozen scenario's hydrogen demand grows faster as traditional demand for hydrogen such as in oil refining increases strongly. The hydrogen demand growth rate in the ERIA–Likely scenario is expected to catch up relative to the ERIA–Frozen rate starting from the 2030–2040 period as the use of e-fuels and ammonia carriers start to take place as part of decarbonisation.

The ERIA–STEPS is where hydrogen demand in the industry sector in ASEAN grows at the weakest rate, i.e. 2.3% CAGR caused by the reduction of hydrogen use in oil refining due to the limited mobility electrification and to the limited use of hydrogen in the production of e-fuels and ammonia carriers.

The ERIA–APS is also where hydrogen produced onsite or captive hydrogen production in the four sectors shall increase at the fastest rate. On the other hand, the ERIA–Likely scenario is where hydrogen produced in the four sectors grows at the slowest rate. This can be explained using the economy of scale argument, i.e. the cost of onsite or captive hydrogen production should drop when production is higher as it tries to catch up with demand. In term of low-carbon hydrogen, for example, the need for hydrogen feedstock to produce e-fuels and ammonia carriers in the ERIA–Likely scenario starts to kick-in after 2030 but the quantity is less than in the ERIA–APS scenario so that the economy of scale of producing low-carbon hydrogen is not high enough to decrease low-carbon hydrogen prices. Therefore, the onsite or captive (low-carbon) hydrogen production in the ERIA–Likely scenario may turn-out lower than in the ERIA–Frozen scenario and ERIA–STEPS, the two scenarios with higher carbon intensities.

- **Configuration and sequencing of hydrogen use, and production are keys for the decarbonisation of hydrogen use in the ASEAN industry sector.**

The forecast hydrogen demand and supply might hide the significance of the composition or configuration of such demand and supply levels from the perspective of hydrogen uses and their appearance sequence, which are essential in analysing their impacts on carbon emissions.

For example, in the ERIA–Frozen scenario, the current conventional use of hydrogen as feedstock in the ASEAN industry sector is assumed to remain the same until the mid 21st century. Under the ERIA–Frozen scenario, such uses do not require that hydrogen be produced from low-carbon intensive routes. The ERIA2APS, on the other extreme, shall see an early appearance of application or uses that require low and low-hydrogen production routes such as ammonia fuels, e-methanol, etc. Moreover, under ERIA–APS, structural changes in hydrogen use and production routes are anticipated, for instance, strong and early mobility electrification that will reduce the need for hydrogen in oil refineries.

ASEAN's 2020 hydrogen use is estimated to emit up to 48 million tons of CO2-eq. Assuming that hydrogen will be produced from unabated natural gas, emissions in the ERIA–Frozen scenario by 2050 would reach 107 tons of CO_2-eq.

By 2050, ERIA–APS should be the scenario that achieves the lowest average emissions factor or intensity followed by ERIA–Likely and then ERIA–STEPS, as more low carbon intensive hydrogen will penetrate the strongest under ERIA–APS compared to the ERIA–Likely scenario and respectively the ERIA–STEPS. However, quantification of the emissions will need a more detailed description of the sequence of the appearance of those uses and a dissection of hydrogen production routes in each of the scenarios, which are beyond the scope of this study.

- **Production of low-carbon or green hydrogen would become much greater when its price is low. Low prices of low-carbon hydrogen will happen when the low-carbon electricity and hydrogen production pathways can reach economies of scale in the most climate-ambitious scenario.**

The ratio of onsite production to hydrogen demand in the ERIA–APS is projected to be highest. What happens in this scenario is the strong increase of hydrogen demand as feedstock that triggers an economic of scale high enough to reduce low carbon hydrogen price.

The decarbonisation imperative that grows from the ERIA–STEPS to ERIA–Likely to ERIA–APS is followed by the increasing share of supply from the merchants. The increasing share of merchants' supply in the decarbonisation function shows therefore the important roles expected from the hydrogen merchants to supply low-carbon hydrogen, which cannot be self-supplied by the studied industry sector.

- **The price of renewable electricity, the necessary land and infrastructure needs, and the price of electrolysers are key factors in estimating the future price of low-carbon or green hydrogen. Other important factors are the price of competing fossil fuels, especially natural gas, and the policies to set prices on carbon.**

Production costs of lower and low-carbon intensive such as blue and green hydrogen in Southeast Asian countries is currently high compared to grey hydrogen. Optimistically, if prices of electricity and electrolysers would go down significantly, it would be only during the 2030–2040 decade, when blue and green hydrogen production costs can be expected to reach comparable levels to those of grey hydrogen. It would be only during the 2040–2050 decade that the production costs of blue and green hydrogen would become cheaper than those of grey hydrogen.

In fact, it is not only the prices of electricity and electrolysers that play important roles in defining lower or low-carbon hydrogen competitiveness. Three other factors include the price of natural gas, a carbon tax, and the necessary land and infrastructure for renewable electricity production. Natural gas prices determine both the competitiveness of steam methane reforming (SMR)-based and electrolysis-based hydrogen. Competitive natural gas prices are amongst the reasons for players in the price-sensitive industry sector to keep on using SMR-based hydrogen.

A carbon tax defines how the different carbon capture technologies will penetrate commercially, which will decrease the carbon intensity of SMR-based hydrogen production. Currently the ASEAN region has no sufficient large-scale single site renewable electricity generation capacity such us solar PV, wind power, or geothermal power. A path of staggered lower and low-carbon hydrogen production such as blue and green hydrogen production and infrastructure development might be the most adequate path in decarbonising hydrogen use in industry. The role of the development of various carbon capture technologies such as carbon capture and sequestration (CCS), carbon capture, utilisation, and storage (CCUS), direct air carbon capture and storage (DACCS) in this pathway is crucial and determining and the implementation of carbon tax is amongst the most effective ways to trigger the development of such technologies.

Nevertheless, the main basic assumptions that need to be considered when estimating the future of hydrogen costs are the price development of the different types of electrolyser technologies and capacities, the development of the different renewable electricity generation costs, and the costs of hydrogen storage and transportation.

In this study, 2,000 MW solar PV and a multi-stack electrolyser facility of 1,500–2,000 MW are assumed to be located next to the industrial plant. Assuming decreases in electrolyser capital and operational expenditure (CAPEX and OPEX), decreasing solar PV-based electricity costs, onsite solar PV based hydrogen production cost might drop from the current US$8–US$13 per kg to reach US$4–US$6 per kg by 2030 and US$2.5–US$ 4 per kg by 2050.

It is important to note, however, that the large land area required for 1–2 GW-scale solar PV farms may necessitate the choice of locations further away from the industrial facilities. In turn, this will require power transmission or hydrogen transport infrastructure and additional contracting costs.

- **Multilateral horizontal and vertical institutional interactions are the two kinds of concurrent and complex interactions that must be considered whilst defining the political economy of hydrogen in ASEAN.**

Finally, a transition towards low-carbon or green hydrogen for Southeast Asia's emerging and transition economics is costly and also requires coordination across governments, multilateral organisations, and industry. Two kinds of concurrent and complex interactions are key determinants of the success or failure of this transition. First, the horizontal interaction between ASEAN governments and policymakers with foreign partner governments, multilateral agencies, and nongovernment organisations. Second, the vertical interaction between government, policymakers, and regulators with domestic companies and international industrial interests in the region.

Horizontally, AMS' governments are encouraged and supported by diverse multilateral organisations, development banks, and partner governments to decarbonise ASEAN economies and achieve their stated policies and announced pledges. Despite the implementational challenges and costs involved and the fact that financial assistance is yet to translate into firm commitments, ASEAN governments have introduced hydrogen into their decarbonisation policies for the next decades.

Whilst horizontal interaction has led ASEAN governments to promote green and blue hydrogen transition projects across the region, vertically, several ASEAN and foreign companies also have announced plans or initiated preparations to shift their industrial hydrogen infrastructure towards blue or green hydrogen in Southeast Asia.

Vertical interactions are nevertheless determined by the characteristics of the involved industrial players including national oil companies, fertiliser and steel companies, as well as domestic and international private corporations, including their ownership structure, financial interests, fragmentation, and their behaviour, i.e. degree of support or resistance towards their low-carbon or green hydrogen transition. These characteristics form different players' strategic and financial interest in their respective sector, and their inherent demands for low-carbon hydrogen and its development.

For instance, national natural gas, oil, and petrochemical companies might show some similarities in their support (or resistance) in terms of low-carbon hydrogen transition, but also differences in their strategies as a function of their domestic natural resources, their degree of state ownership, organisational structure, and international partnerships. The same dynamics also occurs across stakeholder groups such as methanol, ammonia, and steel companies, chemical producers, hydrogen merchants, and different transport sector players, for instance the more dispersed automotive industry in contrast to the more concentrated shipping and airline industries.

2. Recommendations

Based on the above findings, the following list of recommendations are synthesised:

- **ASEAN Member State governments need to reduce renewable electricity costs.**

The price of renewable electricity is one of the key parameters that determine the competitiveness of low-carbon or green hydrogen. Policymakers in ASEAN countries need therefore to elaborate on a set of policy measures to reduce the levelized cost of electricity (LCOE) of renewable resources including related grid infrastructure such as feed-in-tariffs (FIT) that can be considered as amongst the most effective tools. Together with FIT, these policy measures should aim at increasing the domestic industry's capability to produce modules, panels, and other components of renewable-based power plants and at building the skills and capacity of domestic human resources – in other words, reducing the region's dependency on foreign entities or organisations.

Other measures to reduce the LCOE are equally important, for instance, those which enable or ease deployment policies or reduce non-technical costs, such as licensing, permits, grid connection, land management, land acquisition, etc.

In the absence of FIT, one of the most effective ways to reduce the renewable LCOE is to introduce a reverse auction without further price negotiation. Viet Nam is considering replacing their FITs with an inverse auction, whilst the Philippines has just started auctioning their first green energy-based electricity. Indonesia, on the other hand, still equips its maximum purchase price setting with the selection or appointment process of providers followed by a final purchase price negotiation.

- **In the perspective of the political economy, ASEAN Member State governments should build strategies and work on their horizontal and vertical interactions.**

The region's energy, industrial, state-owned enterprises, power, infrastructure, and finance ministries should coordinate and set coherent 'green hydrogen-for-industry transition' taskforces with mandates to work with both domestic and multinational private sector companies and their regional counterparts. With the goal of incentivising state-controlled and private companies to support ASEAN governments' green hydrogen transition, these ministries should work with relevant multilateral agencies, partner governments, and nongovernment organisations to explore possible public and private financing alternatives, including taking advantage of carbon pricing and credit instruments.

ASEAN governments should support their state-controlled companies, including those in the oil and gas, fertiliser, power, and steel sectors, to help promote decarbonisation and a more rapid transition to green hydrogen-based refinery, ammonia, methanol, and steel sectors.

- **ASEAN Member State governments need to elaborate policies to combine public sector co-financing, subsidies, and/or tax breaks with optimal carbon pricing to incentivise the production of low-carbon (green) hydrogen in the near term.**

ASEAN Member State governments should encourage private sector ammonia, methanol, steel, and industrial gas companies to seek all possible financing alternatives, and if necessary, fiscal support to either purchase costlier green hydrogen or to collaborate with renewable electricity companies to co-invest in the large-scale renewable-based electrolysis technologies and infrastructure. Country public budgets can be the practical source of fiscal support, whilst external financing must be considered to increase domestic public co-financing. These must be augmented by external financing promised throughout the United Nations Conference of the Parties (COP) negotiations and following bilateral or multilateral discussions with partner governments, multilateral development banks and institutions, and nongovernment organisations.

Finally, ASEAN Member State governments need to collaborate to accelerate investments in CCS technology and infrastructure based on the least-cost principles to produce blue hydrogen. The cost increases of CCS are in fact moderate, whilst the infrastructure and technological requirements are more incremental. In the meantime, governments need to build detailed cross-industry plans to ensure timely development of large-scale solar PV, wind, geothermal, and other renewable electricity capacities critically necessary to produce the required volume of low-carbon or green hydrogen. In this regard, cross-country regional coordination and cooperation are required to find the optimal regional mix of hydrogen capacities and supply chains, to maximise economies of scale and scope.

- **ASEAN Member States should soon launch low-carbon hydrogen pilot projects, such as producing hydrogen from the surplus electricity generated by variable renewable energy (VRE) resources, including solar photovoltaic and wind or producing it from electricity generated by VRE in remote areas where electricity demand is negligible. In this production pathway, hydrogen plays the role of batteries and/or transportable batteries, thus facilitating penetration of VRE.**

Renewable electricity generated by VRE consists of some surplus electricity in some period of the day. The surplus power can be saved in the battery energy storage system and can also be transformed into hydrogen via electrolysis. In other cases, a lot of less populated remote regions in ASEAN have high renewable energy potential where generated renewable electricity can be fully tapped and transformed into hydrogen. Pilot projects focusing on this 'unused' renewable electricity should be soon conducted by ASEAN Member States to gain techno-economic knowledge on low-carbon hydrogen production, storage, and transportation that should give the information and data needed to elaborate strategies to continuously reduce low-carbon hydrogen production, storage, and transportation costs leading to more commercialised level of production and use.

3. Way Forward

More important details, however, remain to be elaborated. Those details might be addressed by the following research questions, amongst others: How can the costs of the different colour (carbon intensity) of hydrogen be reduced in each scenario during the observed period? Which renewable energy type, project location, and infrastructure configuration stand the best chance to most rapidly decrease the levelized cost of hydrogen for the major industrial facilities in ASEAN? How will the average prices of hydrogen be developed in each scenario during the observed period? How will the average carbon or carbon dioxide (CO_2) emissions factors develop in each scenario during the observed period? How will CO_2 emissions evolve in each scenario during the observed period? Indeed, whilst the greening of hydrogen in the industry sector will significantly reduce CO_2 emissions, the huge amounts of energy and fossil fuels used as inputs across the entire refinery, chemical, steel, and metal processing industries continue producing huge quantities of greenhouse gas emissions. The use of renewable energy and electrification thus play critical roles across all sectors.

These questions lead to a more quantitative modelling or research where demand for hydrogen dependent commodities – whether they are traditional such as fertilisers, transport fuel (gasoline and diesel), methanol, direct reduced iron, and derivative chemistry products – or advanced such as ammonia carriers and e-fuels, be determined as functions of the socio-economic and demographic level of the ASEAN Member States, the prices of the different colours (carbon intensities) of hydrogen, the prices of fossil fuels, and the assumed energy and climate change policies.

Quantitative bottom-up hydrogen economy modelling will be then an ideal follow-up research step. This kind of modelling needs extensive data and estimates, especially on the techno-economic and geographic characteristics of the related technologies, fuels, and energy resources. Therefore, some preliminary data collection activities can be set as preliminary research activities. The inclusion of complete ASEAN Member States' data and information will be indispensable, supported by more extensive literature studies on pricing mechanisms from cases of developed countries.