Chapter 1

Introduction

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Hydrogen gas continues to be extensively used in industrial processes like oil refining, chemicals, fertilisers, and steel production (IEA, 2019). Whilst in the future it is expected to power fuel-cell electric vehicles (FCEV) in some countries, economic considerations and infrastructure limitations have constrained its use in transportation to date. This is expected to change.

On the supply side, competitively priced hydrogen continues to be sourced primarily from steam reforming of natural gas ('grey hydrogen') or coal gasification. Whilst hydrogen from water electrolysis ('green hydrogen') has the potential to compete with transport fuels, especially when petroleum prices are high, it is much more expensive than grey hydrogen used for industry (Ball and Weeda, 2015). However, recent research and pilot projects lead to the expectations that technologies like natural gas reforming combined with carbon capture ('blue hydrogen') and electrolysis of water using renewable-based electricity are gaining prominence and could dominate hydrogen production in the future (APERC, 2018; IEA, 2021a).

On the demand side, industry will continue to be the largest user of hydrogen, far exceeding use in transport. Whilst demand for battery electric vehicles (BEV) including plug-in hybrid vehicles has been rising in recent years due to increased subsidies and expanding charging station networks, the transport and logistics sectors are yet to settle to any dominant technology. Indeed, recent findings indicate a future market split between BEVs dominating the light passenger vehicle markets travelling shorter distances and FCEVs used in heavier, long distance utility vehicles such as trucks and rail (Milton, 2020). Furthermore, the potential of hydrogen gas as a future energy carrier is still being developed.

Given the complex set of factors affecting demand, supply, storage, and transport of hydrogen, the search for an optimal hydrogen development strategy requires an analysis of not only technological and economic variables but also a country's geography, energy demand, and supply situation and, equally importantly, their institutional setup.[1] Only by understanding a country's geography, demographic, and institutional history and the technological and economic determinants of hydrogen demand, supply, storage, and transport can an optimal hydrogen development strategy be formulated.

Industries and countries, just like companies, can become victims of their own success. The literature on innovation incentives is abound with reports on industrial and institutional inertia (Belleflamme and Peitz, 2010). In the automobile sector, for example, the German automobile multinationals have been slower than their Chinese competitors and Tesla in shifting their business models towards electric vehicles. The reason lies in their efficient infrastructure and operations being geared towards internal combustion engine technologies and supply chains and their historically strong political lobbying power (Schüsseler, 2018). The latter leads them to rely on the German government to continue helping them maintain their lead in their existing markets and technologies. As a result, the technologies and market infrastructure including charging networks were not built as rapidly as in China or Tesla's target markets.

[1] Rusli (2013) considers geographic, demographic, economic, and socio-political determinants in developing an optimal energy policy for the oil, gas, and coal industries in Southeast Asia.

1. Background

The grand objective of this study is to contribute to the optimal hydrogen market development strategy for the Association of Southeast Asian Nations (ASEAN) region.

First, the ASEAN region had a population of 660 million and a combined gross domestic product (GDP) of more than US$3.0 trillion in 2020 (ASEAN, 2021). Second, the region's refinery, chemical, and steel sector output and demand for passenger and logistics transportation are concentrated in Singapore, Thailand, Indonesia, Malaysia, and Viet Nam, five countries that makeup the region's largest industrial output and consumption market. Third, ASEAN harbours some of the world's largest natural gas reserves and resources (IEA, 2021a). Fourth, the existing natural gas pipeline networks in Malaysia, Indonesia, Thailand–Myanmar, and Viet Nam offer the potential for a future regional network of gas transport pipelines, the trans-ASEAN natural gas pipeline network, which can be crucial for the region's hydrogen market development (ACE, 2022). Fifth, whilst the hydrogen-consuming industries and the automobile production and supply chains in Thailand and Indonesia dominate the region, they are not over-developed yet and have the potential for significant and rapid growth into the future. The proportion of renewable energy-based electricity generation is small, and ASEAN aims to grow its renewable energy capacity to 23% of primary energy consumption by 2025 (Hamdi, 2020). Thus, the region still holds potential for future adaptation and transformation, to be guided by the right future development strategy and policies for its energy sector including hydrogen.

In line with the Seventh Sustainable Development Goal of the United Nations, ASEAN and East Asian Summit countries need to seriously promote the use of renewable sources, energy efficiency, and energy transition measures to cleaner fuels. The use of new energy technologies such as carbon capture usage and storage (CCUS) or carbon recycling and hydrogen should also be incorporated along with the adoption of clean technologies. Hydrogen technology should play a key role as an alternative to fossil fuels and can be applied across sectors, i.e. the industry sector in the short and medium term and the future power generation and transportation sectors in the long term.

The International Energy Agency (IEA) (2019) pointed out that the top four single uses of hydrogen today are found in the industry sector as feedstock such as in oil refining (33%), i.e. for hydrocracking and hydrotreating as well as for processes in biorefinery, in ammonia production (27%), i.e. for urea and other fertilisers, in methanol and its derivates production (11%), and in steel production via the direct reduction of iron ore (3%). Det Norske Veritas (DNV, 2022) estimates that a total of 90 million tons (MT) of hydrogen was produced in 2020, i.e. 48 MT was used as feedstock to produce ammonia and other chemicals, including methanol, 37 MT was used as feedstock in oil refining, and only around 5 MT was used in the production of direct reduced iron.

The specific goal of this study is to provide a set of policy recommendations for policymakers in the ASEAN Member States to accelerate the process of greening the hydrogen supply in the industry sector as part of an optimal hydrogen market development strategy for the ASEAN region. Hydrogen will play an important role in the energy transition in ASEAN that aims to reach carbon neutrality by the middle of the century.

This specific goal can be broken down into two objectives. The first objective is to understand hydrogen use in the ASEAN countries for the last 5 to 10 years and its current and future supply to the industry sector. In more detail, this objective includes:

- Stocktaking and understanding the current use of hydrogen in the industry sector in the ASEAN countries.
- Reviewing and analysing the current hydrogen sources, production processes, supply mechanisms, and infrastructure in the ASEAN countries.
- Estimating regional hydrogen demand and supply through the different possible scenarios to the horizon 2050.

The second objective is to analyse how the supply of hydrogen in the ASEAN countries can become greener and the associated carbon intensity can be reduced through various production routes, such as methane steam reforming using CCUS, electrolysis with electricity coming from renewable sources in the ASEAN countries, etc. The second objective includes analyses of future production, storage, and transport costs and capacity development along the different production routes.

2. Net-Zero Emissions Targets

The idea of having hydrogen as a future energy source and carrier to mitigate climate change is not new. For example, in 2007, based on a scenario that explores the consequences of more ambitious carbon policies that aim at a long-term stabilisation of the concentration of carbon dioxide (CO_2) in the atmosphere close to 500 parts per million volume by emerging and developing countries and assuming a series of technology breakthroughs that significantly increases the cost effectiveness of hydrogen technologies, in end-use in particular, the European Commission (2007) projected a global move to a hydrogen economy starting on 2030.

That study, which can be considered one of the first comprehensive global energy outlook analyses that emphasise the use of hydrogen for industry, estimates that by 2050 two-thirds of electricity generation from fossil fuels would be in plants equipped with carbon capture and sequestration (CCS). The use of hydrogen would take-off after 2030, driven by substantial reductions in the cost of the technologies for producing hydrogen and the demand-pull in the transport sector. By 2050, hydrogen could provide 13% of final energy consumption, compared to 2% in the reference case. The share of renewable energy in hydrogen production will be 50% and that of nuclear 40%, with around 90% of hydrogen used for transport. Under this scenario, global emissions of CO_2 would be stable between 2015 and 2030 and decrease thereafter. However, by 2050, CO_2 emissions would still be 25% higher than in 1990.

Nowadays, the objective of reaching net-zero emissions targets clearly puts hydrogen together with ammonia as one of the future energy sources and carriers. IEA (2021) for instance considers hydrogen electrolysers, together with advanced batteries and direct air capture and storage (DACCS) as the three biggest innovation opportunities that would make vital contributions to the reductions in CO_2 emissions between 2030 and 2050. The study also considers hydrogen and hydrogen-based fuels, together with energy efficiency, behavioural changes, and electrification, renewables, bioenergy, and CCUS as key pillars of the decarbonisation of the global energy system.

On the supply side, the production of electrolyser-based hydrogen would increase. IEA (2021a) points out how the use of electricity by hydrogen merchants would increase strongly from only 4,000 terawatt hours (TWh) in 2020 to more than 9,000 TWh in 2030 and around 10,000 TWh in 2050, by then equalling around two-thirds of the total energy consumed by hydrogen merchants.

Global hydrogen use is anticipated to expand from less than 90 MT in 2020 to more than 200 MT in 2030 to around 530 MT in 2050. In 2050, around 25% of hydrogen would be produced within industrial facilities (including refineries), and the remainder as merchant hydrogen (hydrogen produced by companies, e.g. industrial gas producers, to sell to others).

The share of low-carbon hydrogen would grow from around 10% in 2020 to almost 100% by 2050; around half of the low-carbon hydrogen produced globally in 2030 will come from electrolysis and the remainder from coal and natural gas with CCUS. By 2030, around 150 MT of low-carbon hydrogen will be produced and consumed and about 850 gigawatts (GW) of electrolysers would be installed around the world. By 2050 these figures should reach 520 MT of produced and consumed low carbon hydrogen with more than 3,000 GW of installed electrolysers capacity.

From the consumption perspective, IEA (2021a) emphasises that low-carbon hydrogen use would expand rapidly after 2030. In the electricity sector, hydrogen and hydrogen-based fuels would be used in co-firing with natural gas and should make around 2% of overall electricity generation in 2050.

In the transport sector, hydrogen and hydrogen-based fuels would mainly fuel long-haul heavy-duty trucks. In shipping, together with advanced biofuels, hydrogen-based fuels such as ammonia would increasingly displace oil. Hydrogen is expected to provide around one-third of fuel use in trucks in 2050 in the net-zero emissions (NZE) target. By the same year, hydrogen-based fuels should also provide more than 60% of total fuel consumption in shipping.

A study by ERIA (Li, Han, and Kimura, 2021) based on a collaboration between ERIA and the Institute for Energy Economics, Japan (IEEJ) did, therefore, seek carbon-neutral pathways for ASEAN countries towards the horizon years 2050 and/or 2060 by applying optimisation approaches to choose low- or zero-emissions technologies under a CO2 emissions constraint and cost minimum objective function.

In the study, hydrogen is represented as amongst the innovative energy technologies, together with ammonia, CCUS direct air capture (DACCS), and biomass energy with CO2 capture and storage (BECCS). These innovative energy technologies are added to conventional low-emissions energy technologies and measures, including energy efficiency and conservation, hydropower, geothermal, nuclear power, and biomass, in the transition period.

In the power generation sector, ammonia and hydrogen together would account for around 26% of the total power to be generated in ASEAN by 2060, which shows the importance of co-firing in future power plants. During the period 2040–2050, co-firing at existing coal- and gas-fired power stations, gas-fired power generation with CCUS, and 100% ammonia-fired power generation are expected to be expanded, and a major share of thermal power generation shifts to 100% ammonia-fired power generation by 2060.

In the scenario where ASEAN countries will reach carbon neutrality by 2050 and 2060 considering the use of a carbon sink, the total power generated from hydrogen-fired power plants would reach nearly 500 TWh by 2060. Electricity generation from 100% hydrogen at gas-fired plants would reach around 200 TWh, whilst power generated by gas-hydrogen co-firing with CCUS would reach around 150 TWh.

When carbon neutrality is reached by 2050 and 2060 but a carbon sink use is not considered, the total power generated from hydrogen fired power plants would reach around 1,000 TWh by 2060, double of the situation when a carbon sink is considered. Without considering a carbon sink use, electricity generation from 100% hydrogen at gas-fired plants would reach around 400 TWh, also double the scenario where a carbon sink use is considered. The part of gas-hydrogen co-firing with CCUS would remain around 150 TWh, like the scenario with a carbon sink. It can be concluded that when carbon neutrality targets become more stringent, i.e. when a carbon sink use is not considered, the role of low-carbon hydrogen across decarbonisation pathways will become critical.

Hence, achieving carbon neutrality cannot rely solely on variable renewable energy (VRE) but necessitates integrating combinations of CO_2 reduction technologies. In addition to switching to VRE, energy efficiency measures, implementation of negative-emissions technologies, and switching towards lower carbon fossil fuels, the ASEAN region's use of hydrogen and ammonia can play important decarbonisation roles in the region.

Finally, apart from perceived significant use of hydrogen in the power sector, namely hydrogen turbine and natural gas-hydrogen co-firing, the ERIA study (Li, Han, and Kimura, 2021) also sees some penetration of the use of hydrogen in various end-use applications, including fuel cell electric vehicles (FCEV), hydrogen-based direct reduced iron–electric arc furnaces, fuel cell ships, hydrogen fuelled aircraft, hydrogen heat for industries, and fuel synthesis (methane, liquid fuel, ammonia).

3. Scope and Structure of the Study Report

Studies offering future energy outlooks, several of which have been described briefly in the previous section, hardly touch the use of hydrogen as feedstock in the industry sector, i.e. oil refining, ammonia and fertiliser industry, methanol production, iron and steel industry. Amongst the reasons is the fact that the primary focus of those studies is to provide an energy analysis, whereby the use of hydrogen as feedstock might not have been analysed in detail.

This study aims to address this uncovered area for two reasons. First, nearly 100% of the current hydrogen use, especially in ASEAN and other emerging economies, is as feedstock in the industry sector, and second, the current hydrogen production routes are important sources of greenhouse gas emissions. By understanding the demand and supply of hydrogen as the industry sector's feedstock in ASEAN countries and being able to make recommendations on how to reduce the current hydrogen carbon intensity, the study is in a position to provide several important elements to increase the economy of scale of hydrogen production starting from its current use in the industry sector and to decrease its carbon intensity under more feasible economic conditions.

The study starts by analysing the historical and current hydrogen demand and supply for the industry sector in the ASEAN countries in Chapter 2. Depending on the available data and information, analysis is conducted on the four sectors: oil refining and chemicals, ammonia and fertiliser industry, methanol industry, and iron and steel industry. The periods of 2015–2020 and 2015–2021 in eight ASEAN Member States (AMS), i.e. Brunei Darussalam (Brunei), Indonesia, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam are studied.

In Chapter 3, several future scenarios are elaborated. The chapter starts with a review of scenarios taken from several most important energy outlook studies that include hydrogen as one amongst the low-carbon technologies, energy sources, and carriers. Four scenarios are elaborated with trends and economic, socio-economic, and technological assumptions and policy measures taken from the reviewed studies. The bottom-up methodology to implement the scenarios is explained where socio-demographic trends and external policy measures are two key factors that determine the demand and supply of hydrogen as feedstock in the four industrial sectors mostly by the intermediary of the effects on technology costs.

Results of the analysis of these scenarios are reported in Chapter 4 starting with country-sectoral level analyses. Scenario assumptions and considered policy measures are explained more in the detail in this chapter than in the previous chapter. At the end of the chapter, an aggregated view of the region's future hydrogen demand and supply is analysed at the ASEAN level.

Chapter 5 presents an overview of the economics of hydrogen by analysing the different studies that cover not only Southeast Asia but also other parts of the world, which estimate the current and future costs of hydrogen that are determined by various factors. Amongst the most important factors are the price of renewable electricity across industries and the price of the different types and capacities of electrolysers which can be distinguished into capital expenditure and operational expenditure. Beyond those two key factors, the necessity to transport, and the different final use of hydrogen such as in industry, i.e. ammonia, refineries, methanol, steel and in the transportation sector, are discussed. Using the most relevant data, estimates, and assumptions, this study calculates a set of future hydrogen prices produced from renewable electricity onsite at the industrial locations.

Chapter 6 presents a discussion on the political economy of hydrogen in the ASEAN region. A transition towards low carbon hydrogen will be expensive for Southeast Asia's emerging and transition economies. Therefore, one would expect the need for strong pressure and support from international and domestic, public and private, and political and economic institutions for ASEAN governments to stand a chance of realising their ambitious decarbonisation objectives. In this chapter the relationships and dynamics of the different players are discussed in term of horizontal and vertical interactions between the region and international policy institutions, governments, and firms. Several determinants of success based on those analysed interactions will be presented at the end of the chapter.

Finally, Chapter 7 provides elements of conclusions of the study and detailed policy recommendations for the ASEAN Member States to increase the economy of scale of the current use of hydrogen as the industry sector's feedstock, to decrease the cost of hydrogen production and procurement, and to allow expansion of its use to help lower the carbon intensity of the region's industry and energy sectors, and thus economies.