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氢能的经济与社会影响：东亚峰会地区案例

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摘要：[目的]近年来，随着氢能发展获得新的动力，分析发展氢能产业对经济和社会的影响，有助于为该领域进一步的政策制定和投资决策提供参考。[方法]鉴于东亚峰会地区在经济增长和绿色能源转型中发挥着日益重要的作用，我们构建了一个需求驱动的氢能供应链模型，以全面、定量地评估该地区氢能发展对经济和社会的影响。[结果]该模型对所需的资本投资、新增就业岗位数量、碳排放的潜在减少量、发展初期所需的补贴，以及对关键能源安全指标的影响等方面进行了估算。[结论]我们发现，氢能发展具有显著的创造就业效应，而且我们的估算表明该地区各国的所需总投资以及财政负担都在可承受范围内。除了大幅减少碳排放之外，其积极的社会影响还包括能源安全指标的总体改善。

关键词：氢能；经济影响；社会影响；ASEAN；东亚峰会

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论文二维码

Economic and Social Impacts of Hydrogen Energy: East Asia Summit Region Case Study

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Abstract: [**Objective**] As hydrogen energy has gained new momentum recently, analyzing the economic and social impacts of developing a hydrogen energy sector can inform further policy formation and investment decision making in this regard. [**Method**] Considering the increasingly important role of East Asia Summit (EAS) region in both economic growth and green energy transition, we developed a demand-driven model for the hydrogen energy supply chains to comprehensively and quantitatively evaluate

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the economic and social impacts hydrogen energy development in the EAS region. [**Result**] This model provides estimates of the capital investment required, the number of new jobs created, the potential carbon emissions reduction, the subsidies needed in the early stages of development, and the impacts on key energy security indicators. [**Conclusion**] We find that hydrogen energy development has a significant job creation effect, and that the total investment the fiscal burden appear to be manageable for countries in the EAS region. In addition to substantial carbon emissions reduction, positive social impacts also include general improvements in energy security indicators.

Key words: hydrogen energy; economic impact; social impact; ASEAN; East Asia Summit

0 Introduction

The transition to a hydrogen economy is critical for decarbonizing global industrial and transportation sectors. Green hydrogen and its derivatives have been widely recognized as a key pillar for decarbonizing the "hard-to-abate" sectors, such as heavy-duty and long-distance transport, steel-making, shipping and aviation[1]. They also provide a new and substantial pathway to enhance the absorption of variable renewable energy, by storing the energy in various chemical forms[2]. Furthermore, hydrogen provides the power sector with a key solution to long-term energy storage at massive scale, while also offers a highly flexible peak power generation capacity[3].

The economic and social impacts of hydrogen energy are critical for policy making. The technical feasibility, economics, environmental impacts as well as the institutional and policy issues of introducing green hydrogen and its derivatives have also been extensively discussed, globally and for the East Asia[4-6]. While green hydrogen faces significant economic challenges such as high costs and infrastructure hurdles, several niche applications are already commercially viable with certain policy support[4,7-9]. In addition, the benefits like reducing greenhouse gas emissions and advancing a low-carbon economy make a strong case for public support[10-11]. However, few studies address the broader implications for economic opportunities, fiscal systems, and energy security in developing a hydrogen sector, leaving policymakers under-informed.

This gap is particularly evident in the East Asia Summit (EAS) region, which includes the Association of Southeast Asia Nations (ASEAN) and its neighboring countries. Guided by the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016–2025 Phase II, ASEAN is actively exploring hydrogen opportunities aligned with global trends. The ASEAN Centre for Energy's 2021 report outlines a phased hydrogen energy roadmap, echoing strategies in the United States, Europe, Japan, South Korea, and China[12-13]. In the EAS region, Japan, China, and South Korea are leading in hydrogen technology and infrastructure development, while Australia is emerging as a top green hydrogen exporter[14-16]. It is noted that current fossil fuels constitute 82% (as of 2022) and 83% (as of 2020) in the total primary energy supply of the ASEAN and EAS regions, respectively. Meanwhile, ASEAN has 29% of its electricity sourced from renewable energy by 2022, with hydropower contributing the majority and variable renewable energy (VRE) taking a tiny fraction at about 4%. The EAS region has an even lower share of renewable energy in electricity generation at about 24% by 2020, with VRE contributing almost half of that fraction at 11%[17-18]. In both ASEAN and EAS regions, VRE has a long way to go to help reach the zero-emission goals and therefore green hydrogen will necessarily be a complementary development with substantial potential.

The existing studies, while focusing on technological and environmental aspects, often overlook the broader economic and social implications[19]. The EAS region, with its special importance in driving global economic growth, industrialization, urbanization, energy structure transition and carbon emissions impact[20], highlights the necessity for region-specific research. Hence, this study endeavors to provide an in-depth analysis of the economic and social impacts of hydrogen supply chains in the EAS region. It quantifies the potential environmental benefits of hydrogen energy adoption across various sectors, providing a comprehensive view of the role of hydrogen energy in achieving sustainability goals in the EAS region. Reducing carbon emissions is a primary motivation for hydrogen energy development[21-22]. It thus forms a critical component of our research.

Our key contributions are threefold:

1) EAS region-wide assessment: Building on the previous work of Li & Kimura[4] on hydrogen-based road transport in the ASEAN region, we explore infrastructure investment needs, fiscal burden impacts, environmental impacts in terms of carbon emissions reduction, and energy security implications. In addition, Tolley et al.[23] noted the potential for significant job creation and shifts in employment dynamics brought by the transition to a hydrogen economy in the United States, sets an example of the necessity of a similar and updated study for the EAS region.

2) Investment and fiscal resource estimation: We estimate the required investment and fiscal resources for hydrogen development in the EAS region. The scale of infrastructure investment is a key concern of both policymakers and businesses. It is estimated that globally the transport and storage infrastructure (excluding the production) for hydrogen would reach about USD 80 billion per year between 2041–2050[24]. Accordingly, several leading countries have introduced investment policies, such as the Green Hydrogen Fund of the EU, the Inflation Reduction Act of the United States, and Contract for Difference (CfD) scheme of Japan. However, studies are rare in this regard, especially for the EAS region. Furthermore, only a few studies concern the fiscal burden brought by subsidizing new and renewable energy in general, such as Scorrano et al.[25] and Chen & Chu[26]. Yet none of them quantified the scale of fiscal burden for the introduction of hydrogen energy. This study bridges the gaps by estimating the investment and fiscal resources likely required in the EAS region.

3) Energy security assessment: This is the first energy security assessment of hydrogen energy development in the EAS region. Although energy security benefits have been examined globally, none have focused on the ASEAN region or the broader EAS region. Drawing on frameworks like that in Tseng et al.[27], which discusses the energy security benefits of hydrogen economy, and the 4A energy security framework proposed in Tongsopit et al.[28] and Li & Chang[29], we assess how hydrogen energy can enhance supply reliability and geopolitical stability in the EAS region. This aspect is particularly pertinent given the EAS region's current energy landscape and the global push towards energy diversification.

By exploring these aspects, our study provides an in-depth exploration of the economic, environmental, and strategic aspects of hydrogen energy supply chains in the ASEAN and EAS regions. It offers valuable insights for academic discussions and serves as a practical guide for informed decision-making in the renewable energy sector. Tailored to the specific contexts of these regions, our work is a crucial reference for future policy formulation and strategic planning.

The rest of the paper is organized as follows: Section 1 conducts a literature review of the economic and social impacts of hydrogen supply chains and existing studies about hydrogen energy development in the EAS region. Section 2 presents our methodology and main models. Section 3 summarizes the input data for our analysis. Section 4 discusses the results of our analysis. Finally, we present the conclusions and policy implications derived from our study.

1 Literature Review

The economic and social impacts of hydrogen energy have garnered significant attention, particularly in developed economies such as the United States, Canada, European countries, and Japan. Discussions have covered investment, employment, economic output, and fiscal burden due to subsidies. However, quantitative studies on Asian economies, except for Japan and South Korea, are rare. This literature review synthesizes recent findings and global perspectives.

1.1 Impacts on the Economy and Investment

The economic and social benefits of hydrogen supply chains are significant. They can improve power grid reliability and social responsibility, and offer economic advantages such as export opportunities, thereby enhancing environmental and social objectives[10]. In Southern Africa, for instance, green hydrogen energy holds the potential to revolutionize agricultural and industrial sectors, create economic value in the energy export sector, and generate green jobs[30]. Moreover, integrating hydrogen in electricity systems can lead to lower end-use costs and reduced congestion management costs[31].

Wietschel et al.[32] provided a foundational estimate of the infrastructure investment required to develop hydrogen supply chains in the EU-25 countries, projecting it to amount to 0.3% of their GDP by 2030. This early work set a benchmark for understanding the scale of investment needed in the transition to a hydrogen-based economy. Köhler et al.[33] further expanded on this by applying the ASTRA model to Germany's hydrogen energy sector, demonstrating increases in GDP, employment and investment, thus indicating the broader economic benefits of hydrogen energy.

Building on this European context, Suwidji et al.[34] extended the discussion to East Asia, highlighting the environmental, social, industrial, and energy security benefits of developing hydrogen energy in countries like China, Japan, and South Korea. This study underscored the region-specific strategies and the multifaceted impacts of hydrogen energy development.

In South Korea, Bae & Cho[35] found that hydrogen energy in the transportation sector could increase exports and investments, positively impacting GDP. This aligns with the broader global trends where hydrogen technologies are becoming economically viable, as seen in the Silva et al.[36] study on Portugal, with increased household consumption, real GDP, and investment due to hydrogen technologies.

Additionally, Lee[37] noted that the introduction of hydrogen energy into the power sector reduced fossil fuel demand, especially coal, and lowered production costs, leading to GDP growth. This highlights the potential of hydrogen energy as a catalyst for economic growth and transition away from traditional energy sources.

1.2 Employment and Job Creation

The development of hydrogen supply chains is not only a significant factor in the transition to cleaner energy but also a substantial driver of job creation and economic growth. The Argonne National Laboratory's Excel-based JOBS H_2 model[38] analyzed the job creation potential of hydrogen refueling stations in California. The study estimated the creation of 90–330 jobs per year due to the development of new stations and up to 1,120 jobs for their operation and maintenance by 2023. Similarly, the JOBS FC model was developed to assess the employment impact of fuel cell applications in various sectors. These models provide a quantitative framework for understanding the employment benefits of hydrogen infrastructure and fuel cell technology.

Leguijt et al.[39] presented a hydrogen demand-driven model to estimate job creation in the Netherlands. With the projected demand for green hydrogen reaching 2.11–4.93 million tonnes by 2050, substantial job creation is expected, both in terms of one-off construction jobs and recurring full-time positions for operation and maintenance.

Australian Government[40] estimated that clean hydrogen exports could directly support 16,000 jobs, with an additional 13,000 jobs from related construction work by 2050. This highlights the potential of hydrogen energy as a significant contributor to employment in the sector.

Tolley et al.[23] explored the effects of the transition to a hydrogen economy in the United States, focusing on job creation, job replacement, and the evolving need for skills and education. This study underscored the broader impact of such a transition on the labor market.

Almansoori & Shah[41] highlighted the role of the hydrogen supply chain network in the United Kingdom, starting with small-sized plants and expanding with demand growth. This development is expected to create new jobs, demonstrating the employment potential of hydrogen infrastructure development.

1.3 Impacts on Fiscal Burden

The development of hydrogen supply chains is closely tied to fiscal policies, particularly through subsidies, which are critical in the early stages of hydrogen energy development. These subsidies aim to address market failures associated with the underpricing of pollution and to facilitate the diffusion of cleaner technologies.

1) Debate on subsidies and pollution pricing

Bridle & Beedell[42] highlighted the debate around whether subsidies for hydrogen technology or direct pricing of pollution would more effectively address environmental concerns. Shamsi et al.[43] proposed that the economic value of carbon emissions reduction by hydrogen energy could be calculated using the social cost of CO_2 emission, such as the current prices in carbon emissions trading schemes.

2) Subsidies for technology diffusion

Trencher et al.[44] and Li et al.[45] emphasized the necessity of financial incentives like subsidies and tax credits for reducing high costs at the early stages of development and mitigating investment risks. Köhler et al.[33] indicated that significant investment, about 300 million Euro, would be required to support the establishment of hydrogen refueling stations in Germany.

3) Impact of CO_2 taxes on cost-competitiveness

Cerniauskas et al.[46] studied the impact of CO_2 taxes on the cost-competitiveness of hydrogen in the transportation and industrial sectors. They found that hydrogen could become cost-competitive by 2025 in the transportation sector, but sector-specific CO_2 taxes would be required for green hydrogen to be also cost-competitive in industrial sectors.

4) Payback period for hydrogen supply chains

Obara & Li[47] evaluated the introduction of hydrogen supply chains using existing pipelines, estimating a payback period of 4.17 years for the Qinghai–Shanghai system, indicating the economic feasibility of such ventures.

5) Spatial differentiation of subsidies

Vom Scheidt et al.[31] discussed how differentiating subsidies for hydrogen production based on spatial criteria could lead to lower end-use costs and decrease congestion management costs by 24%, suggesting that targeted fiscal policies can significantly impact the economics of hydrogen supply chains.

1.4 Impacts on the Environment and Energy Security

The significant environmental benefits and energy security enhancements offered by hydrogen energy range from reducing greenhouse gas emissions and health costs to improving energy system flexibility and security.

1) Environmental and health costs avoidance

Shamsi et al.[43] presented a macro-level simulation model estimating the environmental and health costs avoided by introducing hydrogen energy, particularly in Canada's road transport sector. Their findings suggested that using 1 kg of hydrogen energy in this sector could reduce CO_2 emissions by 11.09 kg. Edwards et al.[48] and Amoo & Fagbenle[49] discussed how hydrogen and fuel cells significantly reduced environmental impact and enhanced energy security, while creating new energy industries.

2) Green hydrogen's role in energy security

Green hydrogen has the potential to contribute to energy security in many ways. Considering its benefits in renewable energy adoption, Wang et al.[50] quantified the flexibility of hydrogen production systems, highlighting their role in integrating renewable sources into the electricity system, thereby improving indigenous supply of clean energy.

Razi & Dincer[51] highlighted the versatility of hydrogen in energy storage, such as decarbonizing industries, substituting fossil fuels in transport, and blending with natural gas. Similarly, Ren et al.[52] examined the impact of different hydrogen pathways on the six dimensions of energy security, using cases from China and Denmark.

Al-Mufachi & Shah[53] proposed the use of hydrogen and fuel cells in decarbonizing heat to improve energy security, especially in countries with high heat demands, such as the United Kingdom. The substitution of fossil fuels in power generation and transport by hydrogen also contributes to reducing subsidies provided to fossil fuels.

1.5 Research Gaps

Research gaps in the field of hydrogen energy, particularly in the ASEAN and EAS regions, have been identified in several key areas:

1) Economic viability and policy needs: Despite Li & Kimura[4] indicating the economic viability of hydrogen-based road transport in ASEAN countries, there is a need for more targeted policies to support this development. The formulation of such policies should be based on a detailed analysis of the economic impacts of hydrogen energy.

2) Fiscal impacts: Existing literature, such as the work of Cherry[54] and McLellan[55], has touched upon potential negative fiscal consequences versus the economic benefits of hydrogen energy, respectively. However, a comprehensive analysis of the fiscal impacts, including cost-effectiveness and financial feasibility specific to the ASEAN and EAS regions, is lacking.

3) Infrastructure investment: While Tolley et al.[23] highlighted the potential for job creation and employment shifts with hydrogen energy development, there is a gap in detailed estimations of infrastructure investment requirements in the ASEAN and EAS regions. This study aims to fill this gap by providing insights into the scale and long-term benefits of investment needed.

4) Environmental impact and carbon emissions reduction: Although studies like Tromp et al.[56] and Van Ruijven et al.[57] explored the environmental impacts of hydrogen energy, there is a need for a region-specific analysis of the role of hydrogen energy in reducing carbon emissions and contributing to sustainability goals in the ASEAN and EAS regions.

5) Energy security implications: Discussions on the energy security benefits of a hydrogen economy, as presented by Tseng et al.[27], need to be expanded to reflect the specific energy landscape of the ASEAN and EAS regions. This study intends to assess how hydrogen energy can enhance energy supply reliability and contribute to geopolitical stability in these regions.

Overall, this study fills critical research gaps by providing an in-depth, multifaceted analysis of hydrogen energy development's economic and fiscal impacts, infrastructure requirements, environmental benefits, and implications for energy security in the ASEAN and EAS regions. The insights gained provide timely and necessary references to policymakers and stakeholders for future policy formulation and strategic planning concerning hydrogen energy.

2 Methodology and Data

This study develops a demand-driven model to provide a systematic view on the low-carbon hydrogen supply chains as well as their downstream applications, so as to deliver estimates on the required investment, fiscal burdens, potential on job creation, carbon emissions and energy security implications in a way that the numbers are intrinsically and quantitatively consistent with each other. To our knowledge, this is by far the first comprehensive and quantitative model to capture the impacts of a low-carbon hydrogen energy sector in the EAS region.

2.1 Study Scope and Hydrogen Supply Chain Components

Our study, illustrated in Fig. 1, examines the development of hydrogen supply chains in EAS countries, including ASEAN, by 2040. The scope encompasses hydrogen production facilities, transport infrastructure, storage, and delivery. Downstream applications in power generation, road transport, industrial energy, feedstock uses, and international hydrogen energy trade are included to estimate the carbon emissions reduction effects. The study does not include hydrogen as fuel for shipping and aviation due to technological adoption uncertainties and data limitations.

The economic and social impact analysis centers on direct impacts such as investment, fiscal subsidies, job creation, and carbon emissions reduction. These impacts arise from the development of hydrogen energy infrastructure, supply chains, and applications across sectors. We acknowledge the significance of induced impacts, such as re-spending of income earned from hydrogen-related activities, although these are not quantified in our current analysis. Additionally, we do not consider job losses in the conventional energy sector.

2.2 Methodological Framework

We employ a demand-driven model (Fig. 2) to provide a basis for our analysis on domestic production and international trade of hydrogen, estimating the scale of the supply chain from production to delivery. The study also extends to cover hydrogen infrastructure that connects the supply of hydrogen to its downstream uses, including hydrogen power generation and hydrogen refilling stations. Accordingly, the necessary investment to build up such a supply chain system as well as the costs of the operation and maintenance of the system are estimated.

This demand-driven model, which endeavors to cover the whole supply chains of green hydrogen for each country, is built on the methodologies of established studies including:

1) Hydrogen demand and supply outlook model developed by ERIA (2020)[58] and ERIA (2022)[59] for the EAS region. The results of this model have provided us a starting point to estimate the outlook of production scales of low-carbon hydrogen in each country of the EAS region;

2) Green hydrogen supply chain cost and Well-to-Wheel (WTW) carbon emissions model developed by Li and Kimura[4], Li & Taghizadeh-Hesary[8,60], and Li et al.[11] These models provide detailed supply chain models with CAPEX and OPEX parameters, so that we are able to estimate the scale of investment in the supply chain infrastructure and the costs of operating it; similarly, the carbon emissions were estimated based on the emission factors from the WTW models; and

3) Following Leguijt et al.[39], we estimate labor

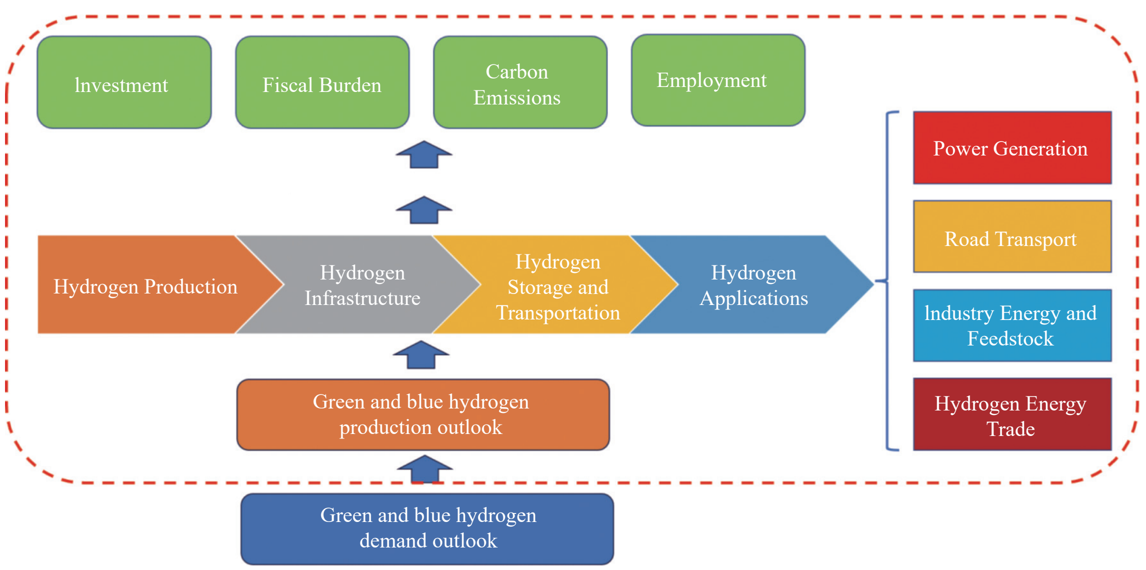

Fig. 1　Scope of the demand-driven model

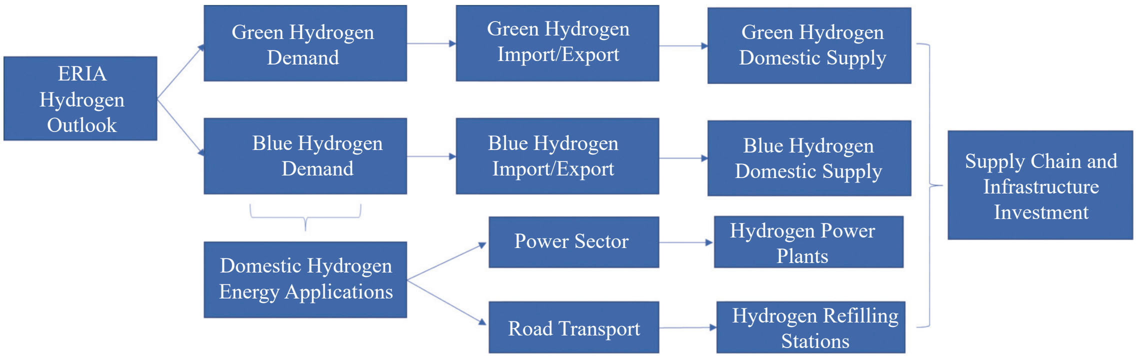

Fig. 2 A demand-driven model of hydrogen supply chain infrastructure

demand for building and maintaining the supply chains. This involves calculating the portion of labor costs from the CAPEX and OPEX of the supply chains and then dividing it by the average labor wage in the country.

2.3 Data and Assumptions

The projected demand and production of hydrogen in our study are based on the findings from the ERIA hydrogen studies titled "Demand and Supply Potential of Hydrogen Energy in East Asia" (phases 1 to 3) conducted in 2019, 2020, and 2022. Additionally, we have considered the capital and operational costs of the hydrogen supply chains as outlined in ERIA's 2020 report, complemented by insights from the ASEAN Centre for Energy[61], Li & Taghizadeh-Hesary[8], and Li et al.[11]

Tab. 1 presents detailed estimations of the hydrogen demand and supply potential in the EAS region for the year 2040. We adopt the demand potential as estimated by the aforementioned ERIA study. However, in estimating hydrogen production, our study deviates from ERIA's original 2022 projections. Our approach involves adapting these assumptions to align with announced government policies and the general trends observed in national energy policies. This adaptation is particularly informed by the considerations regarding the reliance on imported natural gas in these countries.

The proportion of green hydrogen production in each country is assumed to correspond with the share of renewable energy in its primary energy mix by 2040, as projected in ERIA energy outlook[62]. Similarly, the proportion of blue hydrogen production is linked to the share of fossil fuels in the country's primary energy mix. The allocation of specific hydrogen production pathways is expected to mirror the 2040 primary energy mix distributions outlined in the ERIA energy outlook. For determining the relative contributions of solar and wind energy within the total renewable energy mix, we refer to IRENA[63] renewable energy outlook. Hydrogen imports and exports are projected based on ERIA estimations[59].

Labor cost shares in total capital expenditure (CAPEX) and operational expenditure (OPEX) are estimated using data from NREL’s H2A models. Labor wage data is sourced from the International Labor Organization.

Subsidy rates are derived from a variety of sources, including government policy statements, research reports, and academic literature. We assume all subsidy rates will decrease linearly until they are completely phased out by 2030.

Carbon emissions reduction coefficients for hydrogen applications across different sectors are sourced from academic literature, as detailed in Tab. 2. In this study, we consider hydrogen energy in the power sector solely as a storage medium for renewable energy, with green hydrogen functioning as a source for peak power generation. We do not anticipate the use of blue hydrogen for power generation due to its inefficiency and reliance on fossil fuels. Consequently, no carbon emissions reduction effect is attributed to the application of green hydrogen in the power sector.

Due to the lack of reliable data sources to accura-

Tab. 1 Potential for hydrogen production from unused energy compared to hydrogen demand in the EAS countries in 2040[59] (in million normal cubic meters)

Country	Production Potential		Demand Potential	Self-sufficiency Rate from Previous ERIA Study		Our Self-sufficiency Assumptions
	Max	Min		Max	Min	
Australia	21,502	7,169	13,974	154%	51%	154%
Brunei	1	1	1,775	0%	0%	0%
Cambodia	5	1	352	1%	0%	100%
China	1,204	395	163,408	1%	0%	95%
India	1,057	352	11,990	9%	3%	100%
Indonesia	1,501	500	44,807	3%	1%	100%
Japan	–	–	29,252	0%	0%	5%
South Korea	–	–	41,558	0%	0%	76%
Laos	13	3	9	137%	34%	137%
Malaysia	42	16	24,034	0%	0%	100%
Myanmar	49	12	1,263	4%	1%	100%
New Zealand	3,370	1,123	1,065	317%	106%	317%
Philippines	49	16	4,551	1%	0%	100%
Singapore	–	–	15,098	0%	0%	1%
Thailand	192	63	12,993	1%	0%	70%
Viet Nam	85	29	3,668	2%	1%	100%
Total	29,070	9,681	369,796	8%	3%	–

tely forecast the role of hydrogen in transport, storage, and delivery across different countries, the authors have resorted to making arbitrary assumptions, treating these factors uniformly across countries. A similar method is employed in estimating the future distribution of hydrogen energy across various downstream sectors: allocating 25% to the transport sector, 15% to power generation, and 60% to the industrial sector. This approach facilitates a more consistent comparison of results among countries. These assumptions can be updated once more precise data becomes available.

In assessing the impact of hydrogen energy on energy supply security, the study mainly concerns the replacement of fossil fuels, both imported and domestically produced, in accordance with each country's current balance of imports and indigenous production.

3 Analytical Results

3.1 Hydrogen Demand

The projected demand for hydrogen energy by 2040 is expected to be fulfilled through two primary production pathways: green hydrogen and blue hydrogen. These projections are based on the anticipated shares of fossil fuels and renewable energy sources by 2040 as outlined in the ERIA energy outlook. The data illustrated in Fig. 3 shows that, in several countries, the discrepancy between green and blue hydrogen production and total hydrogen energy demand presents drivers

Tab. 2 Carbon emissions reduction coefficients for hydrogen energy applications across various sectors[11,64-67]

	Road Transport		Chemical Industry			Steel Manufacturing
	Gasoline Replacement (kg CO_2/kg H_2)	Diesel Replacement (kg CO_2/kg H_2)	Gray H_2 Replacement (NG) (kg CO_2/kg H_2)	Gray H_2 Replacement (Coal) (kg CO_2/kg H_2)	Gray Ammonia Replacement (kg CO_2/kg H_2 used in producing ammonia)	Replacing Coal (kg CO_2/kg H_2 used in DRI for steel)
Green hydrogen	20.2	7.5	13.0	25.0	11.8	25.0
Blue hydrogen	19.9	7.0	12.5	24.5	10.7	24.0

for trade.

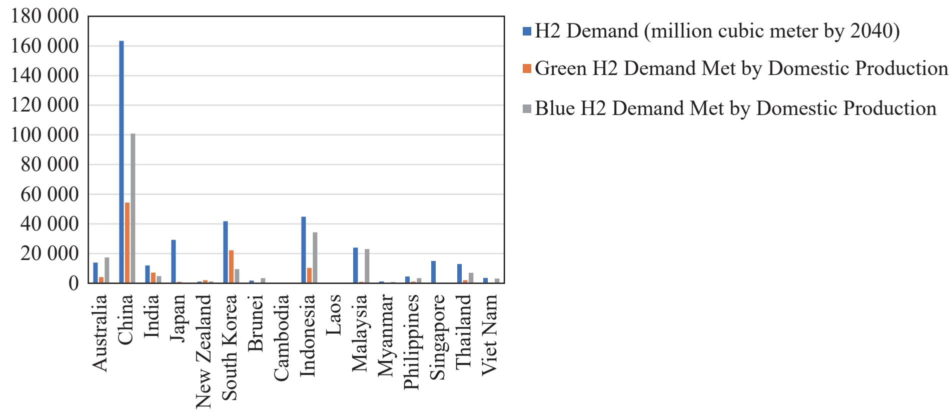

Fig. 3 Hydrogen demand of EAS countries in 2040 (in million cubic meters)

Among the top five hydrogen consumers, China, Indonesia, and Malaysia are projected to be self-sufficient, whereas Japan and South Korea will need to import hydrogen. Japan is anticipated to become a major global hydrogen importer. Several ASEAN countries, including Cambodia, Laos, and Myanmar, exhibit negligible hydrogen demand and production. Despite having the world's largest population, India has a hydrogen demand smaller than that of Singapore and Thailand. As a developed economy, New Zealand has a hydrogen demand remarkably low.

The current projection for hydrogen production anticipates a significant increase in both green and blue hydrogen outputs from now until the year 2040. These projections, illustrated in Fig. 4 and Fig. 5, suggest an exponential growth rate, a pattern that is not unfamiliar when looking at the evolution of renewable energy technologies in recent history. During the early adoption phases of renewable energy, growth was gradual, but as technology advanced and became more widely accepted, the growth rate increased dramatically (IEA, 2022).

Specifically, green hydrogen produced through the electrolysis of water using renewable energy sources, such as wind and solar energy, is expected to scale up from 2035 as these technologies become more cost-effective and as policies shift to favor low-carbon energy sources. Meanwhile, blue hydrogen generated from natural gas with carbon capture and storage (CCS) to reduce emissions is expected to see substantial growth from the current date. This is particularly due to the current infrastructure for natural gas which can be adapted for blue hydrogen production and the increasing emphasis on lowering carbon emissions from fossil fuel use.

The projected difference in growth rates between green and blue hydrogen suggests that by 2040, blue hydrogen production is anticipated to be almost twice the green hydrogen production. This could be attributed to various factors, including the maturing of CCS technologies, policy incentives, and market dynamics favoring blue hydrogen's production methods. However, these projections are contingent upon continued technological advancements, supportive policy frameworks, and sufficient investment in infrastructure and research and development.

The exponential growth trajectory for both types of hydrogen implies significant changes in the energy sector, including advancements in hydrogen storage, transportation, and usage across different industries. Such growth would also indicate a shift towards a more diversified and potentially more sustainable energy mix, with hydrogen playing a pivotal role in global efforts to the transition to cleaner energy sources.

3.2 Investment Costs

The investment costs associated with the develop-

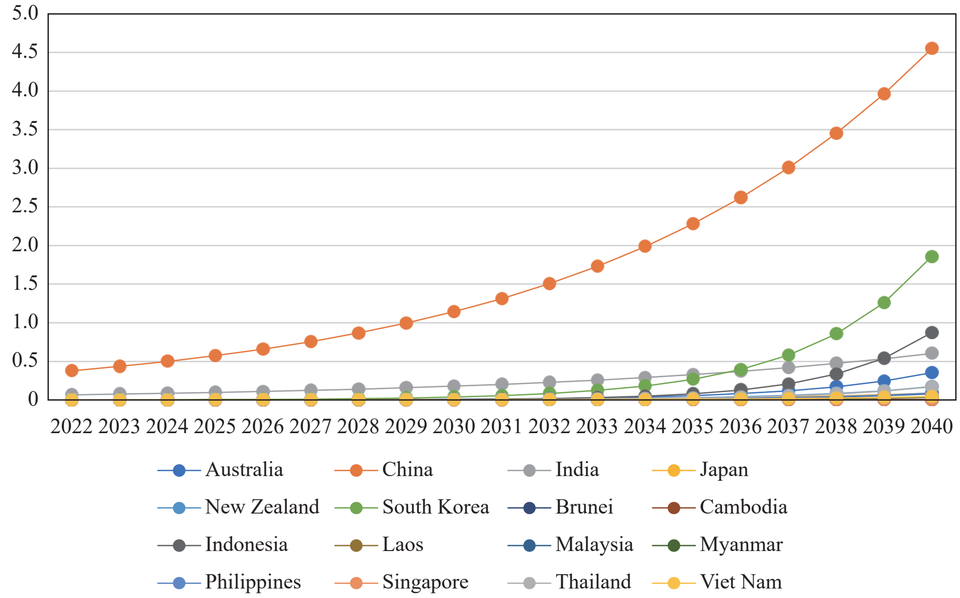

Fig. 4 Green hydrogen production outlook by country (in million tonnes)

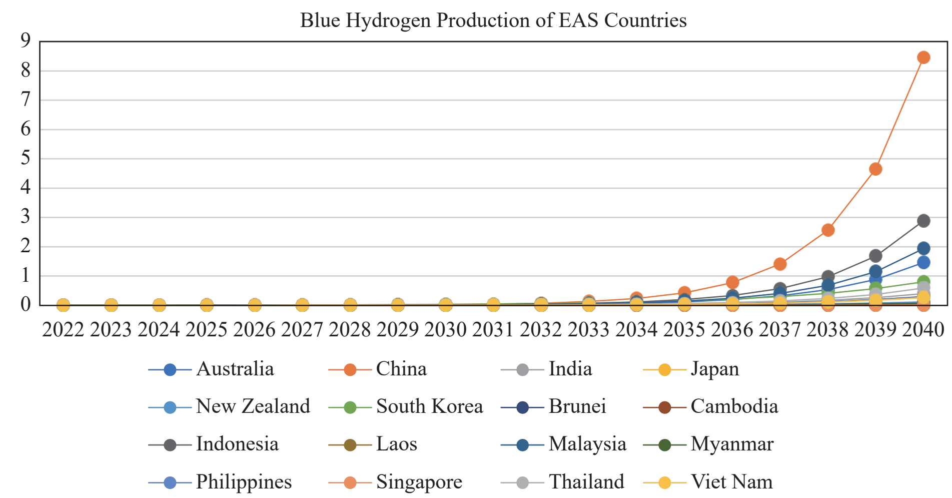

Fig. 5 Blue hydrogen production outlook by country (in million tonnes)

ment of hydrogen energy infrastructure are a critical component of the overall push towards a sustainable energy transition. Fig. 6 delineates the projected capital investment required for establishing the hydrogen supply chains within the ASEAN region and the broader EAS region. In ASEAN countries, there is a clear upward trajectory in investment from a modest USD 30 million in 2023, increasing to a substantial USD 82 billion by 2040. This growth reflects the region's commitment to integrating hydrogen as a key component in its energy mix.

The EAS region demonstrates an even more pronounced investment curve. Starting at about USD 1.9 billion, the investment is expected to increase significantly to an impressive USD 263 billion by 2040. This steep increase is largely propelled by significant financial commitments from China, Japan, and South Korea. These countries collectively account for more than 60% of the total capital investment within the EAS region for hydrogen energy, as indicated in Fig. 7. Their leadership in this domain underscores their strategic focus on hydrogen as a cornerstone for their future energy security and environmental sustainability.

A closer look at the ASEAN region shows

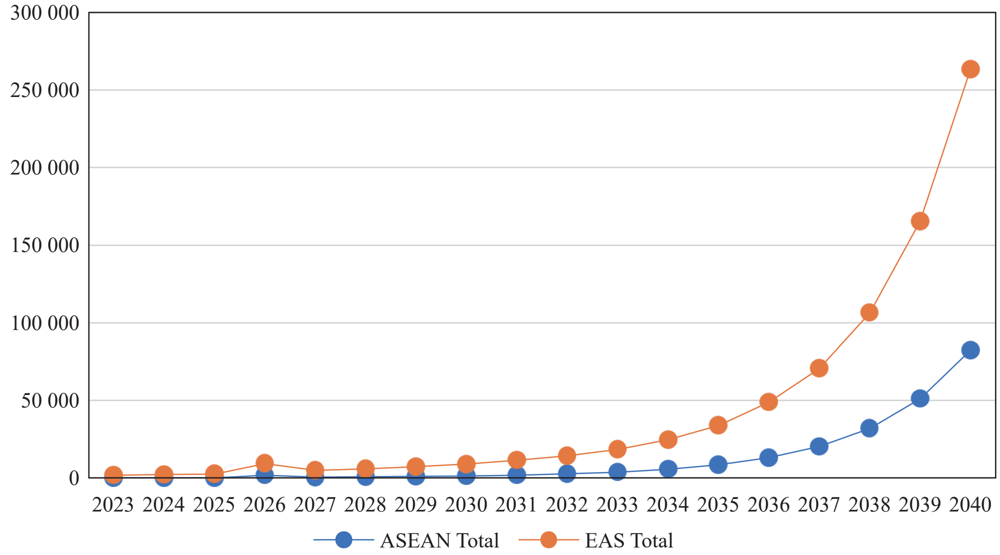

Fig. 6 Capital investment in the hydrogen supply chains (in million USD)

Indonesia, Malaysia, Thailand, and Singapore as key players with considerable investment opportunities in hydrogen energy. The drive in these countries is likely spurred by a combination of factors, including economic growth, the pursuit of energy diversification, and environmental commitments.

The allocation of the investment, as shown in Fig. 8, reveals that a majority, over 70%, is directed towards establishing robust infrastructure for hydrogen transportation, storage, and delivery systems. These are critical components that enable the wide-scale adoption and utilization of hydrogen as a fuel. About 21% of the investment goes to hydrogen production facilities, which are essential at the initial phase of the hydrogen supply chains. The remaining investment is distributed across various applications of hydrogen energy, such as in power generation and the development of hydrogen refilling stations.

Meanwhile, the total capital investment in the EAS region by 2040, adjusted to 2022 dollars, is anticipated to reach USD 263.5 billion. However, this investment represents about only 0.32% of the projected GDP of the EAS region, which stands at USD 81,474 billion in 2022 dollars. This indicates that the financial requirements for advancing hydrogen energy are well within the economic capacity of the EAS region.

3.3 Employment

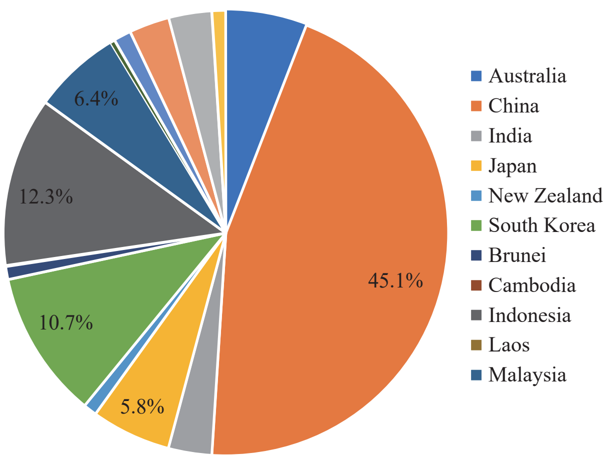

Fig. 7 Hydrogen infrastructure investment by country

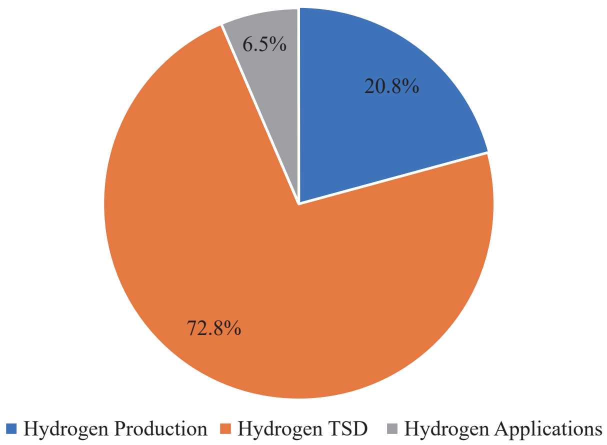

Fig. 8 Hydrogen infrastructure investment by type in the EAS region (2023–2040)

The employment landscape within the hydrogen energy sector is poised for transformation as the industry expands. The first category encompasses one-time jobs, which are largely generated during the construction phase of hydrogen infrastructure and the installation of related facilities. These roles are depicted in Fig. 9. The second category includes recurring jobs, which will arise from the ongoing operations and maintenance needs of the hydrogen supply chains, as illustrated in Fig. 10. Both one-time jobs and recurring jobs are quantified in terms of full-time equivalent (FTE) employment opportunities.

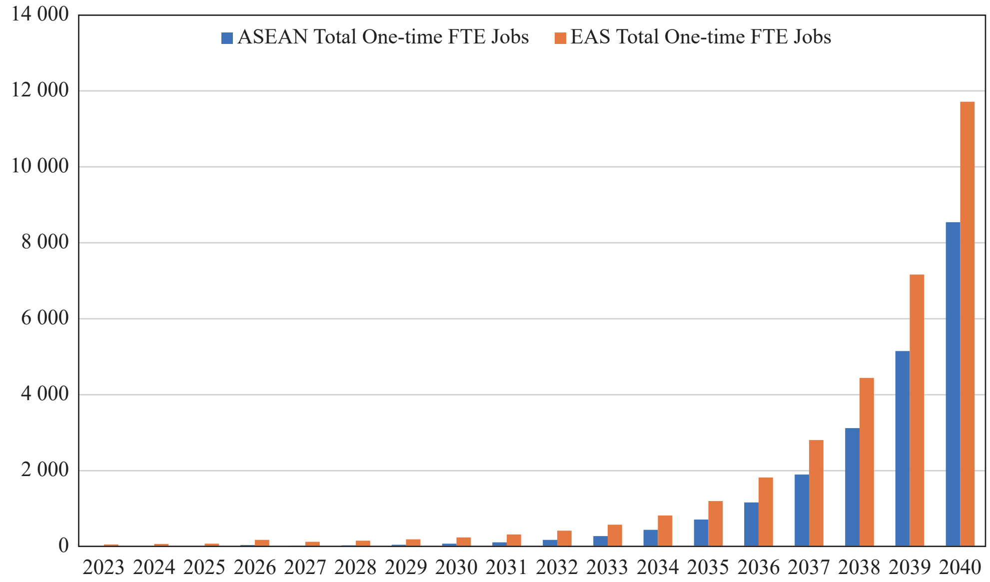

Fig. 9　Total one-time FTE jobs created by the hydrogen energy sector in the ASEAN and EAS regions (in thousands)

By 2040, the EAS region is expected to see the creation of nearly 12 million one-time FTE jobs, attributable to the intensive labor requirements of constructing and setting up new hydrogen facilities. In contrast, over half a million recurring FTE jobs are projected, reflecting the comparatively lower manpower

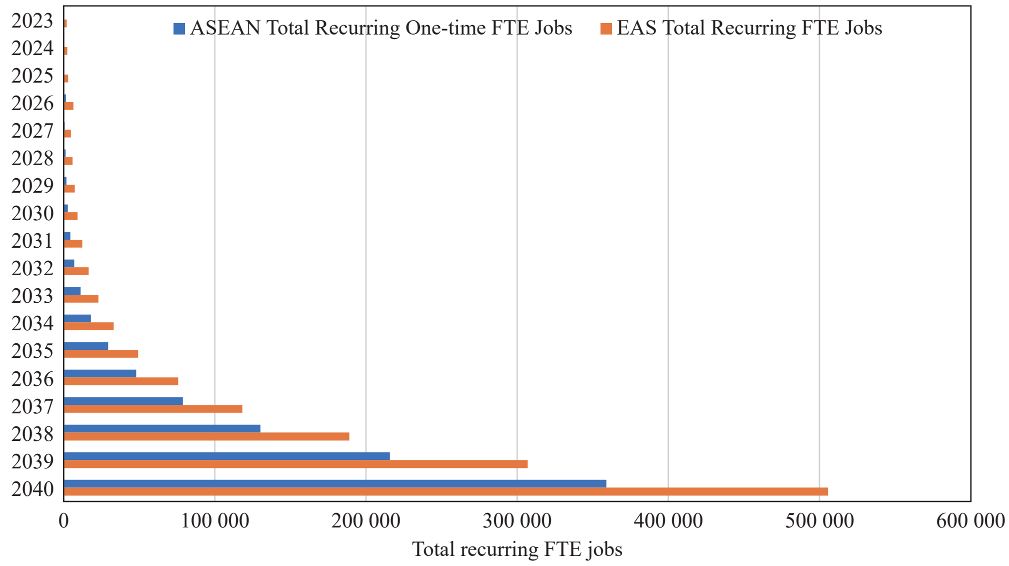

Fig. 10　Total recurring FTE jobs created by the hydrogen energy sector in the ASEAN and EAS regions

needs for sustaining operations and maintenance once the hydrogen infrastructure is in place. This disparity highlights the labor-intensive nature of the construction phase compared to the operational phase of the hydrogen supply chains.

An intriguing aspect of this job creation dynamic is that about 70% of these new employment opportunities within the EAS region are expected to arise in ASEAN countries. This is despite the fact that the scale of the hydrogen energy sector in non-ASEAN countries is significantly larger. A contributing factor to this trend is the lower average wage levels in ASEAN countries, which can make these countries more competitive locations for labor-intensive construction and installation work. The availability of a more cost-effective labor force in these countries may encourage investment in hydrogen infrastructure projects.

Tab. 3 provides a detailed forecast of the two types of FTE jobs for each country in the EAS region by the year 2040. This table is anticipated to reveal the distribution of job creation across the EAS region, reflecting national policies, labor market conditions, and the readiness of each country to adopt hydrogen technologies. The highest number of one-time jobs will occur in Indonesia. The number in Indonesia is three times that in China, despite that the hydrogen production in Indonesia is much smaller than that in China. In addition, Indonesia also has the highest number of recurring jobs, twice that in China. This is mostly driven by Indonesia's much lower labor wage levels than those in other countries.

The expansion of the hydrogen energy sector thus represents not just a transition to cleaner energy sources, but also a significant economic opportunity for job creation. These jobs will range from high-skilled positions in engineering, project management, and technology development to skilled labor roles in construction and trades. Moreover, the operation and maintenance phase will generate a steady stream of jobs that will contribute to the long-term stability and growth of local economies.

Tab. 3 Accumulated one-time and recurring FTE jobs by 2040 in the EAS countries

Country	One-time FTE Jobs	Recurring FTE Jobs
Australia	91,192	3,675
China	2,258,883	107,713
India	554,442	25,146
Japan	77,984	2,842
New Zealand	15,268	577
South Korea	176,270	6,842
Brunei	43,244	1,399
Cambodia	15,894	648
Indonesia	6,810,236	290,099
Laos	262	10
Malaysia	681,623	26,599
Myanmar	117,684	4,256
Philippines	238,630	11,210
Singapore	31,543	1,139
Thailand	398,365	14,534
Viet Nam	206,473	8,991

In addition to direct employment, the hydrogen sector is likely to spur job creation indirectly through supply chain activities and the broader economic stimulation associated with new infrastructure projects. As such, the growth of the hydrogen industry could have a ripple effect, potentially revitalizing communities and bolstering economic development in regions that invest in hydrogen energy infrastructure and technologies.

3.4 Subsidies and Fiscal Burden

Subsidies play a crucial role in the adoption of hydrogen energy technologies. They are typically provided in three categories: subsidies for hydrogen production facilities, subsidies for transport, storage, and delivery infrastructure, and subsidies for hydrogen energy production itself. These subsidies vary depending on the policies of individual countries.

Subsidies for hydrogen production facilities range from 12% to 30% of total CAPEX. Differentiating subsidies based on spatial criteria can result in lower end-use costs and may reduce congestion management costs significantly[31]. However, it is important to note that subsidized grid-connected hydrogen production can sometimes induce additional emissions, potentially at worse rates than those in conventional, fossil-based hydrogen production pathways[68].

The subsidies for hydrogen transport, storage, and delivery infrastructure range from 30% to 50% of total CAPEX. This investment is crucial for establishing a robust hydrogen economy. Subsidizing the unit investment cost of wind turbines, for example, can minimize the levelized cost of hydrogen in most regions[69].

Subsidies for hydrogen energy production range from USD 1/kg to USD 2.9/kg, with variations based on national policies. The dynamic subsidy mode yields better results than the static subsidy mode, such as in increasing hydrogen fuel cell vehicle (HFCV) purchases and market diffusion efficiency[45]. All subsidies are assumed to linearly decrease in rates until they are phased out by 2030. The results are presented in Fig. 11.

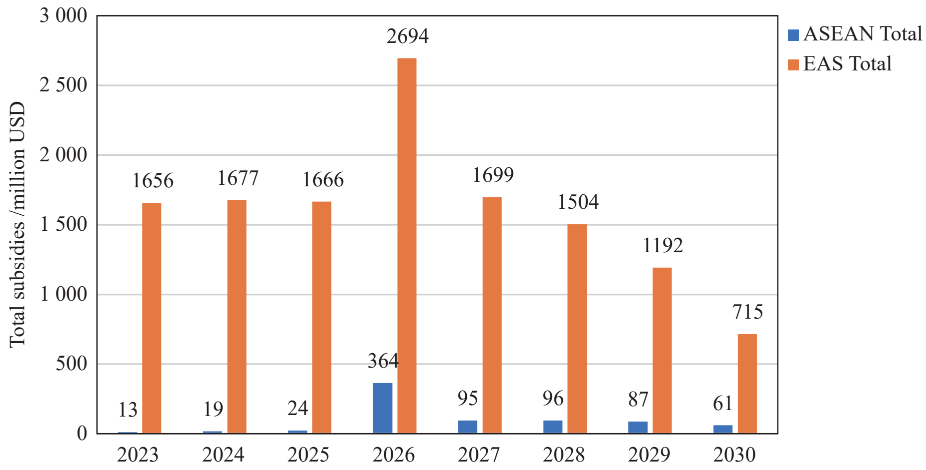

Fig. 11　Total subsidies on hydrogen supply chains in the ASEAN and EAS regions (in million USD)

The total fiscal subsidies amount to USD 12.8 billion across EAS countries from 2023 to 2030, with a significant portion coming from non-ASEAN members. Out of this, USD 759 million is contributed by ASEAN countries. According to World Bank data, the total nominal GDP of the EAS countries in 2021 reached USD 32,811 billion. This means that, even without considering inflation, the fiscal subsidies for hydrogen energy represent only 0.039% of the GDP, or 0.11% of the government fiscal expenditure in the EAS region, based on the corresponding scale in 2021. This means that the fiscal burden to subsidize hydrogen energy should be in a manageable range.

While this represents a small percentage of the GDP or government fiscal expenditure, the long-term benefits in terms of environmental sustainability and reduced reliance on fossil fuels are significant. Hydrogen, being the most environmentally friendly fuel, has the potential to substitute for fossil fuel-based energy infrastructure[70].

3.5　Carbon Emissions Reduction

The substitution of conventional fuels with hydrogen energy offers significant potential for carbon emissions reduction across the EAS region. This study assumes uniform factors of carbon emissions reduction by substituting conventional fuels with hydrogen energy in all EAS countries, as presented in Tab. 2.

The EAS region could see a carbon emissions reduction of about 358 million tonnes, with ASEAN countries contributing more than 100 million tonnes to this reduction (Fig. 12). Research shows that at low load conditions, a hydrogen-diesel dual-fuel engine can reduce carbon emissions by over 90%, a substantial decrease compared to conventional diesel operation[71]. Moreover, switching to HFCV can also significantly reduce other air pollution emissions[72].

Applying the current European ETS carbon price of 85 Euro/tonne, the economic value of the carbon emissions reduction achieved in the EAS region in 2040 alone could exceed 30 billion Euro (about USD 32

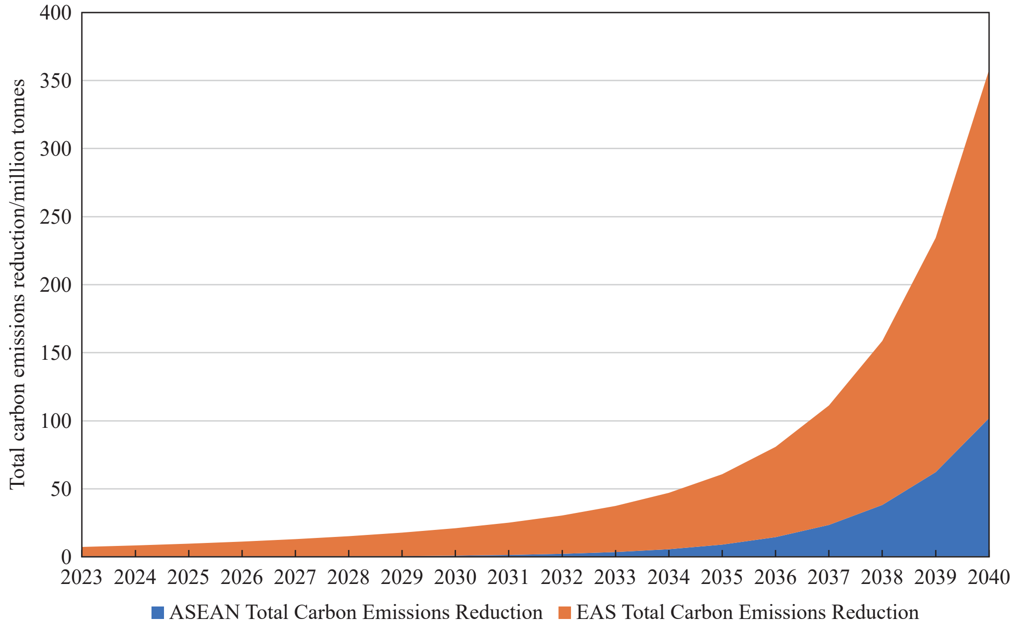

Fig. 12 Total carbon emissions reduction in the ASEAN and EAS regions (in million tonnes)

billion, at an exchange rate of 1 Euro = 1.06 USD). This amount is about 2.5 times the total fiscal subsidies provided for the hydrogen supply chain development in the EAS region between 2023–2030, which amount to about USD 12.8 billion.

3.6 Energy Security

The adoption of hydrogen energy could significantly influence energy security in various ways. Hydrogen production, particularly from excess energy from hydropower stations and wind farms, has potential for energy security and diversification, as evidenced by studies in Brazil as well as elsewhere[73-74]. As green and blue hydrogen increase the use of the corresponding input clean energy for their production, they are increasingly recognized for their role in reducing environmental impact, enhancing energy security, and creating new energy industries[75,48]. In addition, hydrogen energy enhances energy security by minimizing dependence on imports of fossil fuel and diversifying the energy mix[52].

Utilizing the 4As energy security framework[29], which includes availability, applicability, acceptability, and affordability, three key indicators mostly influenced by hydrogen energy are selected: energy mix diversification, indigenous energy supply, and savings in fossil fuel imports (Tab. 4).

Key observations from energy indicators are as follows. (1) In 9 out of the 16 countries surveyed, all three energy indicators show positive changes, indicating improvements in energy security. (2) Negative changes are observed only in the indicator of energy mix diversification, particularly in Brunei, Cambodia,

Tab. 4 Impacts of hydrogen energy on energy security indicators in EAS countries %

Country	Energy Mix Diversification	Indigenous Energy Supply (Self-sufficiency)	Savings in Fossil Fuel Imports
Australia	1.10	1.44	11.84
China	0.46	0.59	2.30
India	0.22	0.14	0.34
Japan	0.11	0.10	0.24
New Zealand	–0.52	1.39	6.23
South Korea	1.81	4.08	6.14
Brunei	–29.48	0.00	0.00
Cambodia	–0.43	0.44	1.14
Indonesia	0.34	0.06	0.56
Laos	18.37	0.02	0.06
Malaysia	–0.18	1.08	0.54
Myanmar	–0.01	0.00	0.00
Philippines	0.22	0.31	1.74
Singapore	–0.04	0.02	0.15
Thailand	–2.79	0.85	1.61
Viet Nam	0.04	0.06	0.23

Malaysia, Myanmar, Singapore, and Thailand. In these countries, the production of blue hydrogen increases the share of coal and natural gas, while the share of renewable energy is not significant enough. (3) Indigenous energy production and savings in fossil fuel imports improve in all countries, except for Brunei and Myanmar that do not import significant amounts of fossil fuel.

4 Conclusions and Policy Implications

This study, through a demand-driven model, offers a comprehensive analysis of the economic and social impacts of hydrogen energy supply chains in the EAS region, including ASEAN countries and other major partners. It provides detailed projections for capital investment, job creation, carbon emissions reduction, early-stage subsidies, and energy security impacts.

We anticipate a significant increase in both green and blue hydrogen production by 2040. Green hydrogen production is projected to reach almost 9 million tonnes per year and blue hydrogen production to reach almost 18 million tonnes per year. This development necessitates over USD 263 billion in annual capital investment across the EAS region. Over 70% of this investment will bolster the infrastructure for hydrogen transport, storage, and delivery, while 21% will focus on production facilities and energy applications. Notably, countries like China, South Korea, Japan, Indonesia, Malaysia, Thailand, and Singapore are poised to lead this investment.

The job market is set to expand remarkably, with nearly 12 million one-time FTE jobs and over half a million recurring FTE jobs expected by 2040. About 70% of these jobs will emerge in ASEAN countries, influenced by comparatively lower wage scales.

The fiscal aspect of this development, involving subsidies until 2030, is projected to be sustainable at USD 12.8 billion accounting for a mere 0.039% of the EAS region's GDP as of 2021. The economic value of the expected carbon emissions reduction by 2040, which is estimated at 358 million tonnes, vastly outweighs these subsidies, emphasizing the financial and environmental viability of hydrogen energy.

Most countries in the EAS region will also see improved energy security, with positive changes in indigenous energy supply and reduction in fossil fuel imports. However, the reliance on blue hydrogen might heighten some countries' dependence on fossil fuels, affecting the energy mix diversification.

Additionally, the economic value of carbon emissions reduction in 2040 is projected to be 2.5 times greater than the total fiscal subsidies required. The study estimates a carbon emissions reduction of about 358 million tonnes in the EAS region, with ASEAN countries contributing over 100 million tonnes to this reduction. Using the current European ETS carbon price of 85 Euro/tonne, the economic value of the carbon emissions reduction in the EAS region in 2040 could exceed 30 billion Euro (equivalent to about USD 32 billion, at an exchange rate of 1 Euro = 1.06 USD).

Most countries in the EAS region will also see improved energy security, with positive changes in indigenous energy supply and reduction in fossil fuel imports. Indigenous energy supply and savings in fossil fuel imports see positive improvements in all countries, except for Brunei and Myanmar as these two countries will remain self-sufficient in energy supply. However, the reliance on blue hydrogen might heighten some countries' dependence on fossil fuels, affecting the energy mix diversification. Energy mix diversification also improves in most countries, but not in Brunei, Cambodia, Malaysia, Myanmar, Singapore, and Thailand. This is because the production of blue hydrogen may intensify a country’s reliance on fossil fuels.

These findings are instrumental for policy-making, indicating that while the capital investment for developing hydrogen energy is substantial, it is also manageable and promises significant job creation. Supportive policies and fiscal subsidies are essential and viable for the growth of the hydrogen energy sector. The profound impact on carbon emissions reduction and national energy security justifies these fiscal support. Policies in the EAS region are recommended to focus on further R&D, economies of scale, and international collaboration to optimize hydrogen supply chains, reducing costs and enhancing the overall efficiency and sustainability of hydrogen energy in the EAS region.

Further research on the comprehensive impacts of hydrogen energy in the EAS region is still required. For instance, country- and industry-specific analysis could present more detailed policy implications to help develop accurate policy tools, so as to maximize the benefits while minimizing possible negative impacts. Alternative scenarios for sensitivity analysis are also necessary, although they are not included in this paper due to the consideration of article length. Data and key assumptions also need to be updated and refined in future research when more information about local hydrogen supply chain projects in countries of the EAS region become available.

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