Chapter 3

Optimal Hydrogen Supply Chain in East Asia

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Chapter 3
Optimal Hydrogen Supply Chain in East Asia

1. Background

As previously stated, hydrogen is produced from fossil fuels and water. Therefore, hydrogen production sites are different from hydrogen consumption sites. The development of a hydrogen supply network – the hydrogen supply chain – is thus key in the EAS region. Based on the hydrogen production of hydrogen-exporting countries, hydrogen consumption of hydrogen-importing countries, distances between hydrogen-exporting and -importing countries, and transport costs, this section outlines optimal hydrogen transport routes and amounts in 2040 when hydrogen will be used commercially as a zero-emission fuel.

2. Optimisation Approach

To find an optimal hydrogen supply chain solution in 2040, the linear programming approach was applied, and its model structure consists of following blocks.

Hydrogen consumption block. This is the hydrogen consumption amount (Nm^3) of hydrogen-importing countries in the EAS region:

$$\sum_i \sum_k X_{jjk} = HC_j \qquad (2)$$

Where:
X_{ijk} = the hydrogen transport amount from exporting country *i* to importing country *j* by transport mode *k,* and
HC_j = hydrogen consumption of importing country *j.*

Hydrogen production block. This is the hydrogen production amount (Nm^3) of hydrogen-exporting countries in the EAS region:

$$\sum_{\boldsymbol{j}} \sum_{\boldsymbol{k}} \boldsymbol{X_{ijk}} = \boldsymbol{HP_i} \qquad (3)$$

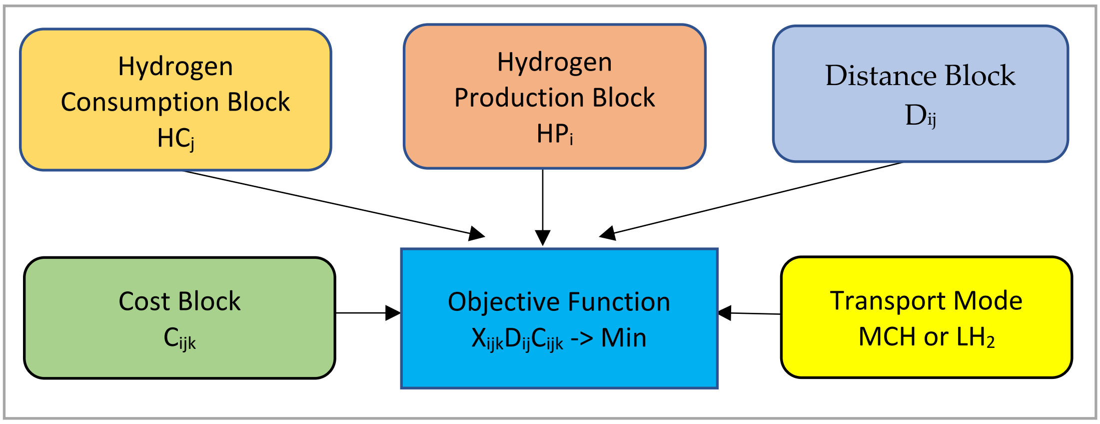
Where:
X_{ijk} = the hydrogen transport amount from exporting country *i* to importing country *j* by transport mode *k,* and
HP_i = hydrogen production amount of exporting country *i.*

Distance block. This is the distance (km) between hydrogen-exporting and -importing countries, where D_{ij} is the distance between hydrogen-exporting country *i* and hydrogen-importing country *j.*

Cost block. This is the hydrogen transport cost ($ per Nm^3 per km) from exporting country *i* to hydrogen-importing country *j* by transport mode *k*, where C_{ijk} is the transport cost from hydrogen-exporting country *i* and hydrogen-importing country *j* by transport mode *k.*
Objective function.

$$\sum_i \sum_j \sum_k X_{ijk} D_{ij} C_{ijk} \quad -> MIN \qquad (4)$$

Figure 3.1. Hydrogen Optimisation – Linear Programming Model



Source: Author.

3. Model Assumptions

3.1 Selection of Hydrogen-Exporting and -Importing Countries

As hydrogen-exporting countries in EAS region, the following five countries and areas were selected for developing the hydrogen linear programming model:

(i) **Australia.** Large potential of fossil fuels (i.e. coal and gas) and variable renewable energy (e.g. solar PV systems).

(ii) **Brunei Darussalam.** Some potential of fossil fuels, such as gas.

(iii) **Indonesia.** Large potential of fossil fuels (i.e. coal and gas) and hydropower.

(iv) **Sarawak, Malaysia.** Large hydropower potential.

(v) **New Zealand.** Large potential of hydropower, wind power, and geothermal power.

In addition, the ports of the five hydrogen-exporting countries and areas were defined:

(i) **Australia.** Port of Melbourne.

(ii) **Brunei Darussalam.** Port of Muara.

(iii) **Indonesia.** Port of Bontang.

(iv) **Sarawak, Malaysia:** Senari Port, Kuching.

(v) **New Zealand:** Lyttelton Port, Christchurch.

The shipped amount of hydrogen from each port in 2040 is outlined in Table 3.1.

Table 3.1. Supply Amount of Hydrogen
(million normal cubic metres)

Country	Amount
Australia	284,313
Brunei Darussalam	26,979
Indonesia	209,603
Malaysia	128,667
New Zealand	22,828

Source: ERIA (2018).

As hydrogen-importing countries in the EAS region, the following five countries were selected for developing the linear programming model:

(i) **Japan.** Replacing gas power generation by hydrogen power generation and internal combustion engine (ICE) by fuel cell vehicles (FCVs).

(ii) **Korea**. Replacing gas power generation by hydrogen power generation and ICE by FCVs.

(iii) **Peninsular Malaysia.** Replacing gas power generation by hydrogen power generation and ICE by FCVs.

(iv) **Singapore.** Replacing gas power generation by hydrogen power generation.

(v) **Thailand.** Replacing gas power generation by hydrogen power generation and ICE by FCVs.

The receiving ports of the five hydrogen exporting countries are outlined below:

(i) **Japan.** Port of Tokyo.

(ii) **Korea.** Port of Incheon.

(iii) **Malaysia.** Port of Kuantan.

(iv) **Singapore.** Port of Singapore

(v) **Thailand.** Khlong Toei Port, Bangkok.

The amount of hydrogen received in each port of the five hydrogen-exporting countries in 2040 is outlined in Table 3.2.

Table 3.2. Demand Amount for Hydrogen

(million normal cubic metres)

Country	Amount
Japan	302,811
Korea, Republic of	193,609
Malaysia	106,474
Singapore	14,707
Thailand	54,788

Source: ERIA (2019a).

3.2. Distance between Hydrogen Shipping Ports and Receiving Ports

Distances between hydrogen-exporting and -importing ports are defined in Table 3.3.

Table 3.3. Distances between Hydrogen Supply and Demand Places
(kilometres)

Origin/Destination	Port of Melbourne, Australia	Port of Muara, Brunei Darussalam	Senari Port, Kuching, Malaysia	Port of Bontang, Indonesia	Lyttelton Port, Christchurch, New Zealand
Port of Tokyo, Japan	9,910.0	4,342.9	6,172.7	5,817.1	11,626.9
Port of Incheon, Korea	11,191.6	3,802.2	5,144.9	5,104.1	12,862.1
Port of Singapore	8,067.3	1,335.3	1,000.1	2,468.7	11,708.3
Port of Kuantan, Malaysia	8,461.8	1,400.1	981.6	2,776.1	12,101.0
Port of Laem Chabang, Thailand	9,617.4	2,340.9	2,137.2	3,648.4	12,917.7
Khlong Toei Port, Bangkok, Thailand	9,741.5	2,465.0	2,261.3	3,772.5	13,041.8

Note: The two Thailand ports are in the Bangkok area, but both ports are very close in case of long-distance transport; thus, both ports are merged into Port Laem Chabang to represent the port of Bangkok.
Source: Ports.com, http://ports.com/sea-route/#/?a=0&b=0&c=Port%20of%20Melbourne&d=Port%20of%20Tokyo (accessed 25 February 2021).

3.3. Hydrogen Transport Costs

Two hydrogen transport methods were applied to the linear programming model: MCH and liquefied hydrogen. The unit cost of hydrogen transport was difficult to set due to varied transport conditions and uncertainties. Thus, under the following assumed conditions and forecasts, the unit cost curves are in Figures 3.2 and 3.3:

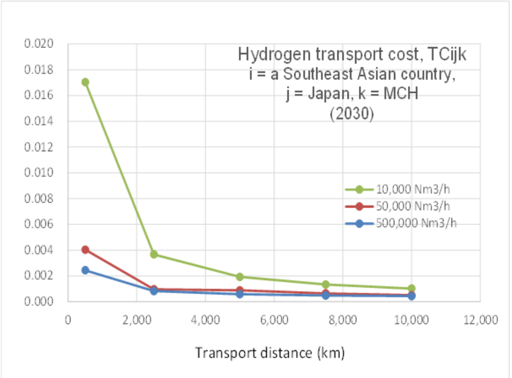
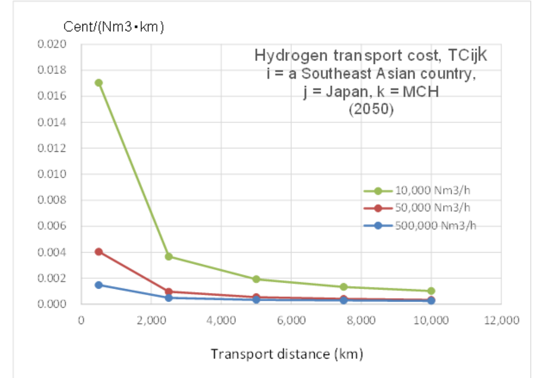
(i) The target years are 2030–2050.

(ii) The transport amounts of hydrogen are equivalent to 10,000 Nm^3/hour, 50,000 Nm^3/hour, and 500,000 Nm^3/hour.

(iii) Transport costs consist of overseas transport by ship – MCH by chemical tankers and liquefied hydrogen by liquid hydrogen ships.

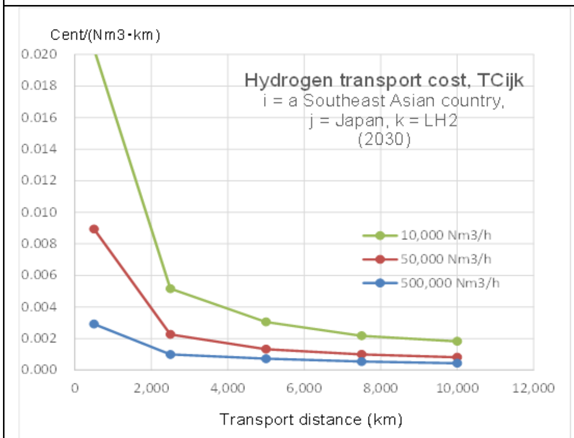
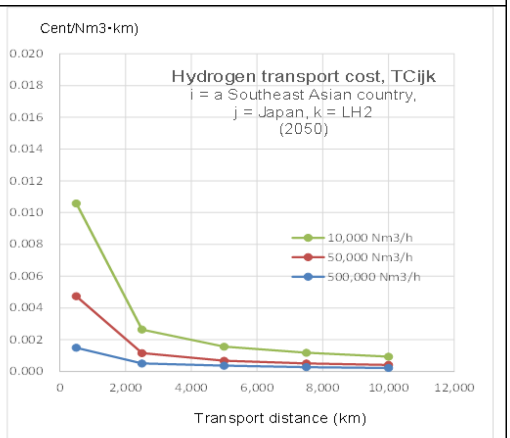
(iv) Distances are 500–10,000 km.

Figure 3.2. Unit Cost of Hydrogen Transport, Methylcyclohexane

2030	2050
	

h = hour, km = kilometre, MCH = methylcyclohexane, Nm^3 = normal cubic metre.
Source: Authors' calculations.

Figure 3.3. Unit Cost of Hydrogen Transport, Liquefied Hydrogen

2030	2050
	

h = hour, km = kilometre, L_2 = liquefied hydrogen, Nm^3 = normal cubic metre.
Source: Authors' calculations.

Hydrogen production costs depend on transport volume and distance. Liquefied hydrogen has an advantage due to its significant volume and long distances. However, small and mid-size hydrogen amounts over short and middle distances are more ideal with MCH.

Referring to Figures 3.2 and 3.3 and calculating an average between 2030 and 2050, the unit cost of hydrogen transport between shipping and receiving ports is defined in Table 3.4.

Table 3.4. Unit Cost of Hydrogen Transport between Shipping and Receiving Ports
(cent/Nm^3-km)

	Japan		Korea		Malaysia		Thailand		Singapore	
	MCH	**LH_2**	**MCH**	**LH_2**	**MCH**	**LH_2**	**MCH**	**LH_2**	**MCH**	**LH_2**
Australia	2.686403	2.201606	2.861701	2.142090	2.448077	2.173979	2.660423	2.203566	2.365271	2.149006
Brunei Darussalam	1.647809	1.766681	1.566005	1.661853	1.448334	1.476336	1.250556	1.299856	1.424133	1.450839
Malaysia	1.982898	2.023305	1.737338	1.876775	1.218762	1.238394	1.375224	1.420450	1.232574	1.252576
Indonesia	1.914345	1.988192	1.726893	1.869389	1.314300	1.372888	1.560495	1.655147	1.247912	1.263364
New Zealand	2.912273	2.103939	3.031016	1.946159	2.962180	2.052039	3.045239	1.917103	2.921226	2.0955795

km = kilometre, L_2 = liquefied hydrogen, MCH = methylcyclohexane, Nm^3 = normal cubic metre.
Source: Authors' calculations.

4. Results of Hydrogen Transport Optimisation Model

4.1. Optimisation of Hydrogen Transport Volume x Distance

First, using the hydrogen linear programming model, the following optimisation approach was conducted for the hydrogen volume x distance:

$$\sum_{i}\sum_{j}\sum_{k} \boldsymbol{X_{ijk}D_{ij}} \quad -> \boldsymbol{MIN} \tag{5}$$

Regarding the optimal calculation results, Australia and New Zealand will export their hydrogen mainly to Japan; Brunei Darussalam and Sarawak, Malaysia will export their hydrogen to neighbouring countries and areas such as Thailand and Peninsular Malaysia. Indonesia will export to Korea and Singapore. However, if Brunei Darussalam's hydrogen exporting amount increases by 1 billion Nm^3, it increases its hydrogen transport to Thailand by 1 billion Nm^3 (i.e. 26,979 to 27,979). Thus, Indonesia will decrease its hydrogen exports to Thailand and increase its exports to Singapore by 1 billion Nm^3; Australia will decrease exports to Singapore and increase exports to Japan; and New Zealand will reduce its exports to Japan by 1 billion Nm^3. As a result, Brunei Darussalam's objective function (i.e. the total transport amount x distance) will decrease 3% – the highest reduction amongst the five hydrogen-exporting countries. In this case study, Brunei Darussalam's hydrogen-exporting volume will be essential when an optimal hydrogen supply chain is sought in the EAS region (Tables 3.5 – 3.10)

Table 3.5. Optimal Hydrogen Transport Solution
(million Nm^3)

	Japan	Korea	Malaysia	Thailand	Singapore	Total Supply	Supply Constraint
Australia	279,984	0	0	0	4,329	284,313	284,313
Brunei Darussalam	0	0	0	26.979	0	26,979	26,979
Malaysia	0	0	106,474	22,193	0	128,667	128,667
Indonesia	0	193,609	0	5,616	10,378	209,603	209,603
New Zealand	22,827	0	0	0	0	22,827	22,828
Calculation	302,811	193,609	106,474	54,788	14,707	4,331,181,398	Volume x distance
Actual Demand	302,811	193,609	106,474	54,788	14,707	672,389	

Nm^3 = normal cubic metre.
Source: Authors' calculations.

Table 3.6. Australia's Increase of 1 Billion Nm^3 of Hydrogen Production
(million Nm^3)

	Japan	Korea	Malaysia	Thailand	Singapore	Total Supply	Supply Constraint
Australia	280,984	0	0	0	4,329	285,313	284,313
Brunei Darussalam	0	0	0	26,979	0	26,979	26,979
Malaysia	0	0	106,474	22,193	0	128,667	128,667
Indonesia	0	193,609	0	5,616	10,378	209,603	209,603
New Zealand	21,827	0	0	0	0	22,827	22,828
Calculation	302,811	193,609	106,474	54,788	14,707	4,329,464,498	Volume x distance
Actual Demand	302,811	193,609	106,474	54,788	14,707	672,389	

Nm^3 = normal cubic metre.
Note: The reduction ratio of the objective function compared to Table 3.5 is –0.04%.
Source: Authors' calculations.

Table 3.7. Brunei Darussalam's Increase of 1 Billion Nm^3 of Hydrogen Production

(million Nm^3)

	Japan	Korea	Malaysia	Thailand	Singapore	Total Supply	Supply Constraint
Australia	280,984	0	0	0	3,329	284,313	284,313
Brunei Darussalam	0	0	0	26,979	0	27,979	26,979
Malaysia	0	0	106,474	22,193	0	128,667	128,667
Indonesia	0	193,609	0	5,616	11,378	209,603	209,603
New Zealand	21,827	0	0	0	0	21,827	22,828
Calculation	302,811	193,609	106,474	54,788	14,707	4,198,216,893	Volume x distance
Actual Demand	302,811	193,609	106,474	54,788	14,707	672,389	

Nm^3 = normal cubic metre.

Note: The reduction ratio of the objective function compared to Table 3.5 is –3.10%.

Source: Authors' calculations.

Table 3.8. Sarawak, Malaysia's Increase of 1 Billion Nm^3 of Hydrogen Production

(million Nm^3)

	Japan	Korea	Malaysia	Thailand	Singapore	Total Supply	Supply Constraint
Australia	280,984	0	0	0	3,329	284,313	284,313
Brunei Darussalam	0	0	0	26,979	0	26,979	26,979
Malaysia	0	0	106,474	23,193	0	129,667	129,667
Indonesia	0	193,609	0	4,616	11,378	209,603	209,603
New Zealand	21,827	0	0	0	0	21,827	22,828
Calculation	302,811	193,609	106,474	54,788	14,707	4,322,354,698	Volume x distance
Actual Demand	302,811	193,609	106,474	54,788	14,707	672,389	

Nm^3 = normal cubic metre.

Note: The reduction ratio of the objective function compared to Table 3.5 is –0.20%.

Source: Authors' calculations.

Table 3.9. Indonesia's Increase of 1 Billion Nm^3 of Hydrogen Production
(million Nm^3)

	Japan	Korea	Malaysia	Thailand	Singapore	Total Supply	Supply Constraint
Australia	280,984	0	0	0	3,329	284,313	284,313
Brunei Darussalam	0	0	0	26,979	0	26,979	26,979
Malaysia	0	0	106,474	22,193	0	128,667	128,667
Indonesia	0	193,609	0	5,616	11,378	210,603	210,603
New Zealand	21,827	0	0	0	0	21,827	22,828
Calculation	302,811	193,609	106,474	54,788	14,707	4,323,865,898	Volume x distance
Actual Demand	302,811	193,609	106,474	54,788	14,707	672,389	

Nm^3 = normal cubic metre.
Note: The reduction ratio of the objective function compared to Table 3.5 is –0.17%.
Source: Authors' calculations.

Table 3.10. New Zealand's Increase of 1 Billion Nm^3 of Hydrogen Production
(million Nm^3)

	Japan	Korea	Malaysia	Thailand	Singapore	Total Supply	Supply Constraint
Australia	279,984	0	0	0	4,329	284,313	284,313
Brunei Darussalam	0	0	0	26,979	0	26,979	26,979
Malaysia	0	0	106,474	22,193	0	128,667	128,667
Indonesia	0	193,609	0	5,616	10,378	209,603	209,603
New Zealand	22,827	0	0	0	0	22,827	23,828
Calculation	302,811	193,609	106,474	54,788	14,707	4,331,181,398	Volume x distance
Actual Demand	302,811	193,609	106,474	54,788	14,707	672,389	

Nm^3 = normal cubic metre.
Note: The reduction ratio of the objective function compared to Table 3.5 is 0.00%.
Source: Authors' calculations

4.2. Optimisation of Hydrogen Transport Costs

If the optimal calculation results in regard to the transport mode of hydrogen are analysed, Australia exports its hydrogen to Japan through liquefied hydrogen, and Brunei Darussalam exports its hydrogen to Japan and Thailand by MCH. Sarawak, Malaysia exports its hydrogen to Peninsular Malaysia and Thailand by MCH. Indonesia exports to Korea, Peninsular Malaysia, and Singapore by MCH. New Zealand exports its hydrogen to Korea by liquefied hydrogen. Japan and Korea import hydrogen from Brunei Darussalam and Indonesia by MCH, but this can be replaced by liquefied hydrogen, because the cost difference is negligible.

A sensitivity analysis was then conducted in which each hydrogen-producing country increases its hydrogen production by 1 billion Nm^3. There is no effect for Australia, because hydrogen demand in Japan remains unchanged. Brunei Darussalam only increases its hydrogen exports to Japan by 1 billion Nm^3. Sarawak, Malaysia increases its hydrogen exports to Thailand by 1 billion Nm^3, altering Brunei Darussalam's exports by decreasing them to Thailand and increasing them to Japan.

A change in New Zealand's production brings more complicated changes to the hydrogen supply chain. This increases exports to Korea; as a result, Indonesia decreases exports to Korea and increases exports to Peninsular Malaysia. Sarawak, Malaysia thus decreases hydrogen transport to Peninsular Malaysia, thus increasing exports to Thailand. Finally, Brunei Darussalam's exports to Thailand decrease, but they increase to Japan. Regarding the impact to the reduction of the objective function, Brunei Darussalam has the highest at 0.05%, followed by Sarawak, Malaysia at 0.04% and Indonesia at 0.03%. Cost reduction effects are not significant.

Table 3.11. Optimal Solution of Transport Cost Model
(million Nm^3)

	Japan		Korea		Malaysia		Thailand		Singapore		Total Supply	Supply Constraint
	MCH	LH_2	MCH	LH_2	MCH	LH_2	MCH	LH_2	MCH	LH_2		
Australia	0	284,313	0	0	0	0	0	0	0	0	284,313	284,313
Brunei Darussalam	18,498	0	0	0	0	0	8,480	0	0	0	26,979	26,979
Malaysia	0	0	0	0	82,359	0	46,308	0	0	0	128,667	128,667
Indonesia	0	0	170,781	0	24,115	0	0	0	14,707	0	209,603	209,603
New Zealand	0	0	0	22,828	0	0	0	0	0	0	22,828	22,828
										Total Transport Cost	1,220,485	Total
Total Result	18,498	284,313	170,781	22,828	106,474	0	54,788	0	14,707	0	672,389	672,389
Total Demand		302,811		193,609		106,474		54,788		14,707	672,389	12,205

L_2 = liquefied hydrogen, MCH = methylcyclohexane, Nm^3 = normal cubic metre.
Source: Authors' calculations.

Table 3.12. Australia's Increase of 1 Billion Nm3 of Hydrogen Production
(million Nm^3)

	Japan		Korea		Malaysia		Thailand		Singapore		Total Supply	Supply Constraint
	MCH	LH_2	MCH	LH_2	MCH	LH_2	MCH	LH_2	MCH	LH_2		
Australia	0	284,313	0	0	0	0	0	0	0	0	284,313	285,313
Brunei Darussalam	18,498	0	0	0	0	0	8,480	0	0	0	26,979	26,979
Malaysia	0	0	0	0	82,359	0	46,308	0	0	0	128,667	128,667
Indonesia	0	0	170,781	0	24,115	0	0	0	14,707	0	209,603	209,603
New Zealand	0	0	0	22,828	0	0	0	0	0	0	22,828	22,828
										Total Transport Cost	1,220,485	Total
Total Result	18,498	284,313	170,781	22,828	106,474	0	54,788	0	14,707	0	672,389	673,389
Total Demand		302,811		193,609		106,474		54,788		14,707	672,389	12,205

L_2 = liquefied hydrogen, MCH = methylcyclohexane, Nm^3 = normal cubic metre.
Note: The reduction ratio of the objective function compared to Table 3.11 is –0.05%.
Source: Authors' calculations.

Table 3.13. Brunei Darussalam's Increase of 1 Billion Nm^3 of Hydrogen Production

(million Nm^3)

	Japan		Korea		Malaysia		Thailand		Singapore		Total Supply	Supply Constraint
	MCH	LH_2	MCH	LH_2	MCH	LH_2	MCH	LH_2	MCH	LH_2		
Australia	0	283,313	0	0	0	0	0	0	0	0	283,313	285,313
Brunei Darussalam	19,499	0	0	0	0	0	8,480	0	0	0	27,979	27,979
Malaysia	0	0	0	0	82,359	0	46,308	0	0	0	128,667	128,667
Indonesia	0	0	170,781	0	24,115	0	0	0	14,707	0	209,603	209,603
New Zealand	0	0	0	22,828	0	0	0	0	0	0	22,828	22,828
										Total Transport Cost	1,219,931	Total
Total Result	19,499	283,312	170,781	22,828	106,474	0	54,788	0	14,707	0	672,389	673,390
Total Demand		302,811		193,609		106,474		54,788		14,707	672,389	12,199

L_2 = liquefied hydrogen, MCH = methylcyclohexane, Nm^3 = normal cubic metre.
Note: The reduction ratio of the objective function compared to Table 3.11 is –0.05%.
Source: Authors' calculations.

Table 3.14. Malaysia's Increase of 1 Billion Nm^3 of Hydrogen Production

(million Nm^3)

	Japan		Korea		Malaysia		Thailand		Singapore		Total Supply	Supply Constraint
	MCH	LH_2	MCH	LH_2	MCH	LH_2	MCH	LH_2	MCH	LH_2		
Australia	0	283,312	0	0	0	0	0	0	0	0	283,312	284,313
Brunei Darussalam	19,499	0	0	0	0	0	7,480	0	0	0	26,979	26,979
Malaysia	0	0	0	0	82,359	0	47,308	0	0	0	129,667	129,667
Indonesia	0	0	170,781	0	24,115	0	0	0	14,707	0	209,603	209,603
New Zealand	0	0	0	22,828	0	0	0	0	0	0	22,828	22,828
										Total Transport Cost	1,220,056	**Total**
Total Result	19,499	283,312	170,781	22,828	106,474	0	54,788	0	14,707	0	672,389	673,390
Total Demand		302,811		193,609		106,474		54,788		14,707	672,389	12,201

L_2 = liquefied hydrogen, MCH = methylcyclohexane, Nm^3 = normal cubic metre.
Note: The reduction ratio of the objective function compared to Table 3.11 is –0.04%.
Source: Authors' calculations.

Table 3.15. Indonesia's Increase of 1 Billion Nm³ of Hydrogen Production
(million Nm^3)

	Japan		Korea		Malaysia		Thailand		Singapore		Total Supply	Supply Constraint
	MCH	LH_2	MCH	LH_2	MCH	LH_2	MCH	LH_2	MCH	LH_2		
Australia	0	283,312	0	0	0	0	0	0	0	0	283,312	284,313
Brunei Darussalam	19,499	0	0	0	0	0	7,480	0	0	0	26,979	26,979
Malaysia	0	0	0	0	81,359	0	47,308	0	0	0	128,667	128,667
Indonesia	0	0	170,781	0	25,115	0	0	0	14,707	0	210,603	210,603
New Zealand	0	0	0	22,828	0	0	0	0	0	0	22,828	22,828
										Total Transport Cost	1,220,152	Total
Total Result	19,499	283,312	170,781	22,828	106,474	0	54,788	0	14,707	0	672,389	673,390
Total Demand		302,811		193,609		106,474		54,788		14,707	672,389	12,202

L_2 = liquefied hydrogen, MCH = methylcyclohexane, Nm^3 = normal cubic metre.
Note: The reduction ratio of the objective function compared to Table 3.11 is –0.03%.
Source: Authors' calculations.

Table 3.16. New Zealand's Increase of 1 Billion Nm³ of Hydrogen Production
(million Nm^3)

	Japan		Korea		Malaysia		Thailand		Singapore		Total Supply	Supply Constraint
	MCH	LH_2	MCH	LH_2	MCH	LH_2	MCH	LH_2	MCH	LH_2		
Australia	0	283,312	0	0	0	0	0	0	0	0	283,312	284,313
Brunei Darussalam	19,499	0	0	0	0	0	7,480	0	0	0	26,979	26,979
Malaysia	0	0	0	0	81,359	0	47,308	0	0	0	128,667	128,667
Indonesia	0	0	169,781	0	25,115	0	0	0	14,707	0	209,603	209,603
New Zealand	0	0	0	23,828	0	0	0	0	0	0	23,828	23,828
										Total Transport Cost	1,220,371	**Total**
Total Result	19,499	283,312	169,781	23,828	106,474	0	54,788	0	14,707	0	672,389	673,390
Total Demand		302,811		193,609		106,474		54,788		14,707	672,389	12,204

L_2 = liquefied hydrogen, MCH = methylcyclohexane, Nm^3 = normal cubic metre.
Note: The reduction ratio of the objective function compared to Table 3.11 is –0.01%.
Source: Authors' calculations.

5. Implications

Hydrogen is a future clean combustion fuel that can replace fossil fuels, which are used for heat and fuel demand in industry, transport, and power generation. However, hydrogen supply costs are currently expensive; these must be reduced through the expansion of hydrogen demand (i.e. scale merit). In addition, the development of innovative hydrogen production and transport technologies will help reduce hydrogen supply costs.

A hydrogen value chain – to connect both hydrogen production and demand sites – must be established. As mentioned, two hydrogen transport modes are available, MCH and liquefied hydrogen. Generally, MCH has an advantage in short and middle distances and small and mid-volumes. Yet liquefied hydrogen has advantages with middle to long distances and mid- to large volumes. The linear programming model shows similar results; if Australia and New Zealand transport their hydrogen to Japan and Korea, a hydrogen supply network can be established within ASEAN. Brunei Darussalam and Indonesia can still transport their hydrogen to Japan and Korea.

These results depend on assumed hydrogen transport costs, which are based on distance and volume. Appropriate hydrogen transport costs of both transport modes were assumed, but there were many uncertainties. Therefore, the hydrogen transport costs must be further examined to obtain more reliable numbers.

In addition, this study did not include hydrogen production costs before and after treatment of MCH and liquefied hydrogen, which are hydrogenation and dehydrogenation of MCH, and liquefaction and regasification of liquefied hydrogen.