Chapter 3

Estimation of Hydrogen Demand Potential in the East Asia Summit Region

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Chapter 3

Estimation of Hydrogen Demand Potential in the East Asia Summit Region

This chapter estimates hydrogen's demand potential, as well as its ability to compete with conventional fuels and its CO_2 reduction effect. There are many uncertainties regarding the hydrogen supply chain due to varying promotion policies, utilisation technologies, transportation/distribution logistics, and costs. In addition, there is no conventional study of hydrogen demand, such as the International Energy Agency's (IEA) World Energy Outlook (WEO). For these reasons, this study refers to various available resources, including the Economic Research Institute for ASEAN and East Asia's (ERIA) energy outlook, as well as the latest hydrogen utilisation and technology trends, and other demand estimation documents (these reference materials are described in Appendix 3.1).

This study only estimates hydrogen demand potential for energy use, and does not include its use as a feedstock. Although ammonia is regarded as a hydrogen carrier and its direct combustion has been demonstrated, it is excluded in this study. Furthermore, hydrogen supply through onsite natural gas reforming is also excluded because it can be classified as natural gas demand.

The three demand scenarios projected here are grouped by sector—electricity generation, industry and transport – as shown in Table 3.1:

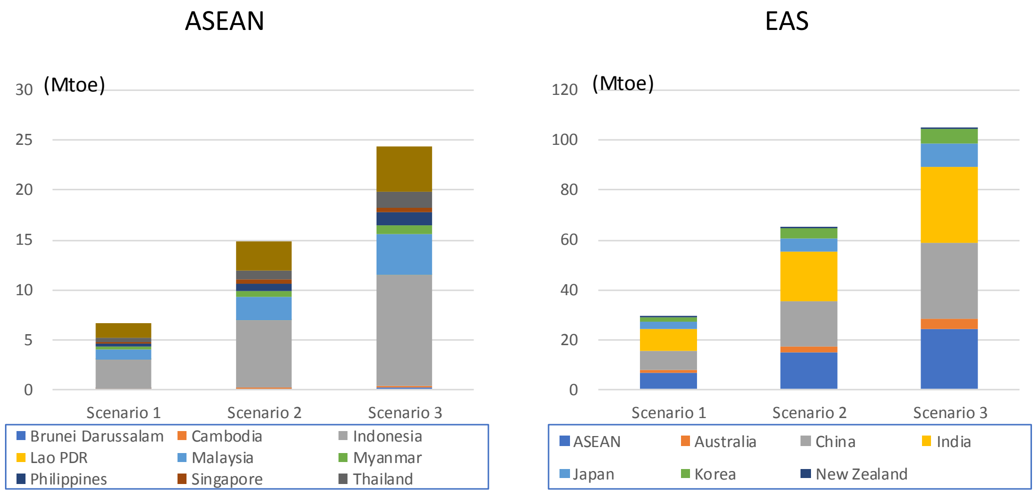
Table 3.1 Summary of Assumptions/Scenarios

Sector	Fuel		Scenario 1	Scenario 2	Scenario 3
Electricity generation	Coal	20% of new coal-fired electricity generation will be converted to natural gas and H_2 mixed fuel-fired generation	H_2 concentration of mixed fuel		
	Natural gas	20% of new natural gas-fired electricity generation will be converted to natural gas and H_2 mixed fuel-fired generation	H_2: 10% Nat. gas: 90%	H_2: 20% Nat. gas: 80%	H_2: 30% Nat. gas: 70%
Industry	Natural gas	20% of natural gas consumption for industrial purposes will be replaced by natural gas and H_2 mixed fuel			
Transport	Gasoline	Passenger Fuel Cell Vehicle: Gasoline demand will be converted to H_2	Share of H_2/ gasoline for passenger cars		
			OECD H_2: 2.0% Gasoline: 98% Non-OECD H_2: 1.0% Gasoline: 99%	OECD H_2: 10% Gasoline: 90% Non-OECD H_2: 5% Gasoline: 95%	OECD H_2: 20% Gasoline: 80% Non-OECD H_2: 10% Gasoline: 90%
	Diesel	Fuel Cell Bus: Diesel demand will be converted to H_2	Share of H_2/ diesel for buses		
			Japan H_2: 0.05% Gasoline: 99.95% Other countries H_2: 0.025% Gasoline: 99.975%	Japan H_2: 0.1% Gasoline: 99.9% Other countries H_2: 0.05% Gasoline: 99.95%	Japan H_2: 0.2% Gasoline: 99.8% Other countries H_2: 0.1% Gasoline: 99.9%
	Diesel	Fuel Cell Train: Diesel consumption for rail transport will be converted to H_2	Share of H_2/ diesel for rail transport		
			H_2: 5% Diesel: 95%	H_2: 10% Diesel: 90%	H_2: 20% Diesel: 80%

OECD = Organisation for Economic Co-operation and Development.
Source: Author.

Figure 3.1 further shows that, by 2040, the potential Association of Southeast Asian Nations (ASEAN) hydrogen demand is 6.6 million tonnes of oil equivalent (Mtoe) in Scenario 1, 14.9 Mtoe in Scenario 2, and 24.4 Mtoe in Scenario 3. The potential East Asia Summit (EAS) region demand is 28.9 Mtoe in Scenario 1, 64.9 Mtoe in Scenario 2, and 104.7 Mtoe in Scenario 3. Indonesia has the largest hydrogen demand potential amongst ASEAN member countries, followed by Malaysia and Viet Nam. China has the largest hydrogen demand potential in the EAS region, followed by India and ASEAN total.

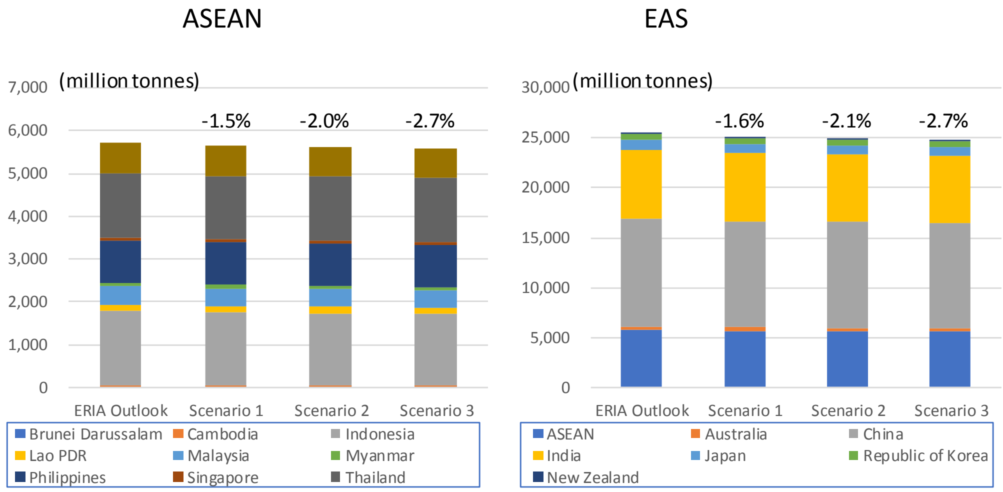
Figure 3.1 Hydrogen Demand Potential in 2040, by Country



ASEAN = Association of Southeast Asian Nations, EAS = East Asia Summit, Lao PDR = Lao People's Democratic Republic, Mtoe = million tonnes of oil equivalent.
Source: Author.

As shown in Figure 3.2, CO_2 emissions can be reduced by up to 2.7% depending on the scenario. Indonesia has the largest CO_2 emissions reduction potential in ASEAN member countries, while India has the largest CO_2 emissions reduction potential, despite being the second-largest EAS CO_2 emitter.

Figure 3.2 Total CO_2 Emissions from Fuel Combustion by Country



ASEAN = Association of Southeast Asian Nations, EAS = East Asia Summit, ERIA = Economic Research Institute of ASEAN and East Asia, Lao PDR = Lao People's Democratic Republic.
Source: Author.

1. Basic Assumptions for Hydrogen Demand Estimation

Although it is difficult to foresee future hydrogen supply chain developments, Table 3.2 shows the study's basic assumptions.

Table 3.2 Basic Assumptions for Estimation of Hydrogen Demand Potential

The national hydrogen pipeline, as well as refuelling stations, will only be partially established in 2040.
Ammonia, which is a hydrogen carrier, is excluded, as well as hydrogen for generating ammonia and/or methanol.[1]
Commercialised hydrogen utilisation technologies in 2040: ● Hydrogen and natural gas mixed fuel gas turbine ● Hydrogen and natural gas mixed fuel large scale boiler ● Passenger fuel cell vehicle ● Fuel cell bus ● Fuel cell train
Technology needing development by 2040: ● Utility scale fuel cell ● Heavy-duty fuel cell vehicle ● Fuel cell ship Technically available, but international and domestic refuelling infrastructures will only be partially established in 2040.

[1] Currently, most ammonia production is for nitrogen fertiliser. If ammonia were to be used for energy, its demand would be one or two times greater than its current level, thus affecting its global supply/demand balance (Institute of Energy Economics, Japan, October 2015).

Note: Distributed fuel cell systems are not included in this study because hydrogen would not be supplied directly without a functioning pipeline. Hydrogen for a distributed fuel cell system would be produced from on-site natural gas reforming, categorising it as part of natural gas demand.

Source: Author.

2. Hydrogen Demand Potential for Electricity Generation

This section assesses the potential demand by 2040 for different scenarios of hydrogen-fired electricity generation under the basic assumption that a mixture of natural gas and hydrogen is used as a generator fuel. Compared to conventional fossil fuels, hydrogen emits lower CO_2, especially when produced from renewable energy. Furthermore, hydrogen combustion emits no particulate matter or sulphur oxide, thus aiding regional environmental and human health.

2.1. Assumptions and Scenario

Table 3.3 shows the assumptions and scenarios to estimate hydrogen demand potential for electricity generation.

Table 3.3 Assumptions and Scenarios of Electricity Generation

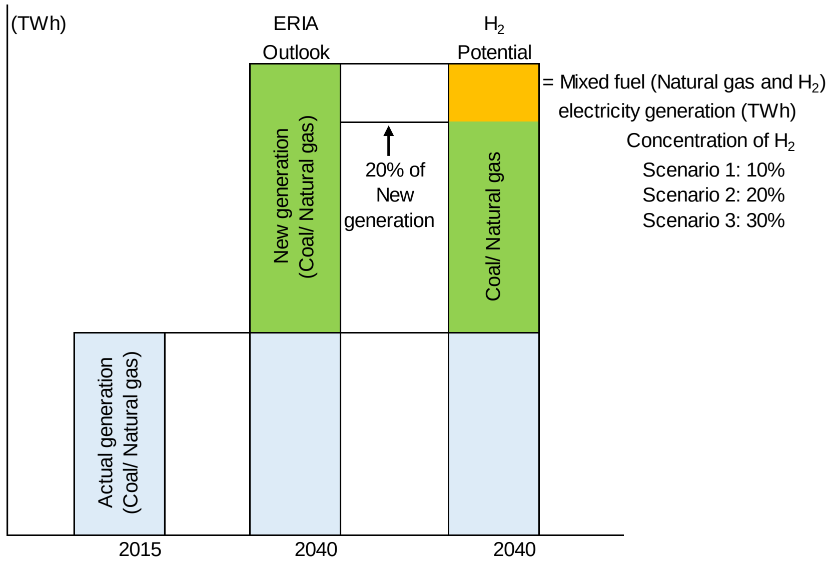
Fuel	Assumed hydrogen use in 2040	Hydrogen concentration in mixed fuel (calorific value basis)
Natural gas	20% of new natural gas-fired electricity generation will be converted to natural gas and hydrogen mixed fuel-fired generation	Concentration Scenario 1: 10% Scenario 2: 20% Scenario 3: 30%
Coal	20% of new coal-fired electricity generation will be converted to natural gas and hydrogen mixed fuel-fired generation	

Source: Author.

Thanks to large recent investments to meet rapidly growing demand, existing fossil-fired power plants in non-Organisation for Economic Co-operation and Development (OECD) countries are relatively young, meaning it is assumed that they will keep operating through 2040. Because of this, the necessary amount of new coal-fired or new natural gas-fired power plants, in terms of energy (kWh), is defined as the difference between electricity demand in 2015 (actual) and 2040 (prospective).

On the other hand, for OECD countries, the age of existing fossil-fired power plants is relatively old due to stagnant or even decreasing electricity demand. Therefore, electricity generation in 2040 is regarded as new. Figure 3.3 outlines the assumptions and scenarios.

Figure 3.3 Outline of Assumptions and Scenarios for Electricity Generation



ERIA = Economic Research Institute of ASEAN and East Asia.
Source: Author.

Based on recent technological developments, hydrogen concentration in a mixed fuel is assumed to be as much as 30%, which MHPS, one of the major utility-scale gas turbine manufacturers, has successfully demonstrated. MHPS's next challenge is developing a pure hydrogen-burning gas turbine. However, considering the reported difficulty of even a 10% increase in the concentration of hydrogen in a mixed fuel, it is safe to assume that a pure hydrogen-burning gas turbine will not be commercialised before 2040. (See Box 3.1.)

10%: 5%–15% concentration is capable with some modification of existing gas turbine technology. (IEA, World Energy Outlook 2017)

20%: Existing gas turbine technology can be applied. (MHPS)

30%: Demonstration succeeded. (MHPS)

Box 3.1 Challenges for Burning Higher Hydrogen-Content Fuel in Gas Turbines

In cases of 20% hydrogen concentration, existing gas turbines can be used; however, 30% hydrogen concentration poses quite a challenge for the gas turbine engineer, due to the following considerations:

- Flashback

  Flashback is a phenomenon where the flames inside the combustor travel up the incoming fuel and leave the chamber. Since hydrogen burns rapidly, flashback commonly occurs.

- NOx

  Fuel and air are mixed prior to entering the combustor. While this enables low-NOx combustion, flashback occurs more frequently when the hydrogen concentration in fuel increases. By securing the required distance, sufficient mixing can be accomplished while also achieving low NOx, but this ends up increasing the flashback risk.

- Combustion pressure fluctuation

  Temperatures inside the combustor reach 1,600 °C, and it is known that imposing an extremely high thermal load on the cylinder results in a very loud noise due to its specified eigenvalue.

Source: MHPS, https://www.mhps.com/special/hydrogen/article_1/index.html

2.2. Hydrogen Demand Potential in Electricity Generation

Table 3.4 shows the assumptions of thermal efficiency and hydrogen specification to calculate hydrogen demand potential.

Table 3.4 Assumption of Thermal Efficiency and Hydrogen Specification

Thermal efficiency *1	Coal: 55% Natural gas: 63% Hydrogen: 63%
Hydrogen specification*2	Gas density: 0.0835 kg/m^3 Net calorific value: 10,780 kJ/m^3 = 2,575 kcal/m^3 = 30,834 kcal/kg = 3,884 m^3/toe

Source: *1 High Efficiency of Thermal Power, November 2017, Agency for Natural Resources and Energy, Ministry of Energy, Trade, and Industry (Japanese only).
*2 Iwatani Corporation.

Table 3.5 shows the estimated hydrogen demand potential for electricity generation by country in 2040 (the calculation method is described in Appendix 3.2).

Table 3.5 Hydrogen Demand Potential for Electricity Generation by Country in 2040
(in Mtoe)

Country	Scenario 1	Scenario 2	Scenario 3
Brunei Darussalam	0.0	0.1	0.1
Cambodia	0.0	0.1	0.1
Indonesia	1.9	3.9	5.8
Lao PDR	-	-	-
Malaysia	0.6	1.1	1.7
Myanmar	0.1	0.2	0.3
Philippines	0.3	0.6	0.9
Singapore	0.1	0.2	0.3
Thailand	0.2	0.5	0.7
Viet Nam	1.1	2.1	3.2
ASEAN	**4.4**	**8.7**	**13.1**
Australia	0.7	1.4	2.1
China	4.8	9.7	14.5
India	7.4	14.8	22.3
Japan	2.0	4.0	6.0
Republic of Korea	1.5	3.1	4.6
New Zealand	0.0	0.1	0.1
Other than ASEAN	**16.5**	**33.1**	**49.6**
EAS Region Total	**20.9**	**41.8**	**62.7**

ASEAN = Association of Southeast Asian Nations, EAS = East Asia Summit, Lao PDR = Lao People's Democratic Republic, Mtoe = million tonnes of oil equivalent.
Note: Lao PDR has no plan to introduce natural gas; thus, the assumption is that coal will not be replaced by hydrogen and natural gas mixed fuel. Calculation method is shown in Appendixes. The same applies hereafter.
Source: Author.

3. Hydrogen Demand Potential for Heat Demand in Industry

In this section, the potential demand for hydrogen-based heat in industry is estimated.

3.1. Assumption and Scenario

Table 3.6 shows the assumption and scenario of industry's potential hydrogen demand. In general, the estimation method is almost the same as for the electricity generation sector, with industry assumed to consume hydrogen as a natural gas mixture, rather than pure hydrogen, for generating heat.

Table 3.6 Assumption and Scenario of Hydrogen Demand Potential for Industry

Fuel	Assumed hydrogen use in 2040	Hydrogen concentration in mixed fuel (on the basis of calorific value)
Natural gas	- Small-scale natural gas/hydrogen mixed-fuel pipelines will be created in industrial parks located near natural gas/hydrogen mixed-fuel-combusting electricity generation plants. - Natural gas for industrial boilers will be replaced by natural gas/hydrogen mixed fuel in areas near mixed-fuel pipelines. - 20% of natural gas consumption for industrial purposes is assumed to be replaced by natural gas/hydrogen mixed fuel.	Same fuel for electricity generation is used for industrial boilers. Concentration Scenario 1: 10% Scenario 2: 20% Scenario 3: 30%

Source: Author.

3.2. Hydrogen Demand Potential for Heat Demand in Industry

Table 3.7 shows the hydrogen demand potential for industry by country in 2040 (the calculation method is described in Appendix 3.3).

Table 3.7 Hydrogen Demand Potential in Industry Sector in 2040 (in Mtoe)

Country	Scenario 1	Scenario 2	Scenario 3
Brunei Darussalam	-	-	-
Cambodia	-	-	-
Indonesia	0.3	0.5	0.8
Lao PDR	-	-	-
Malaysia	0.3	0.5	0.8
Myanmar	0.0	0.1	0.1
Philippines	0.0	0.0	0.0
Singapore	0.0	0.1	0.1
Thailand	0.2	0.4	0.6
Viet Nam	0.1	0.3	0.4
ASEAN	**0.9**	**1.8**	**2.8**
Australia	0.2	0.3	0.5
China	1.8	3.6	5.4
India	0.7	1.3	2.0
Japan	0.3	0.6	0.9
Republic of Korea	0.2	0.4	0.7
New Zealand	0.0	0.0	0.1
Other than ASEAN	**3.2**	**6.4**	**9.5**
EAS Region Total	**4.1**	**8.2**	**12.3**

ASEAN = Association of Southeast Asian Nations, EAS = East Asia Summit, Lao PDR = Lao People's Democratic Republic, Mtoe = million tonnes of oil equivalent.
Note: Brunei Darussalam, Cambodia, and Lao PDR have no industrial natural gas demand projected for 2040.
Source: Author.

4. Hydrogen Demand Potential for Transport

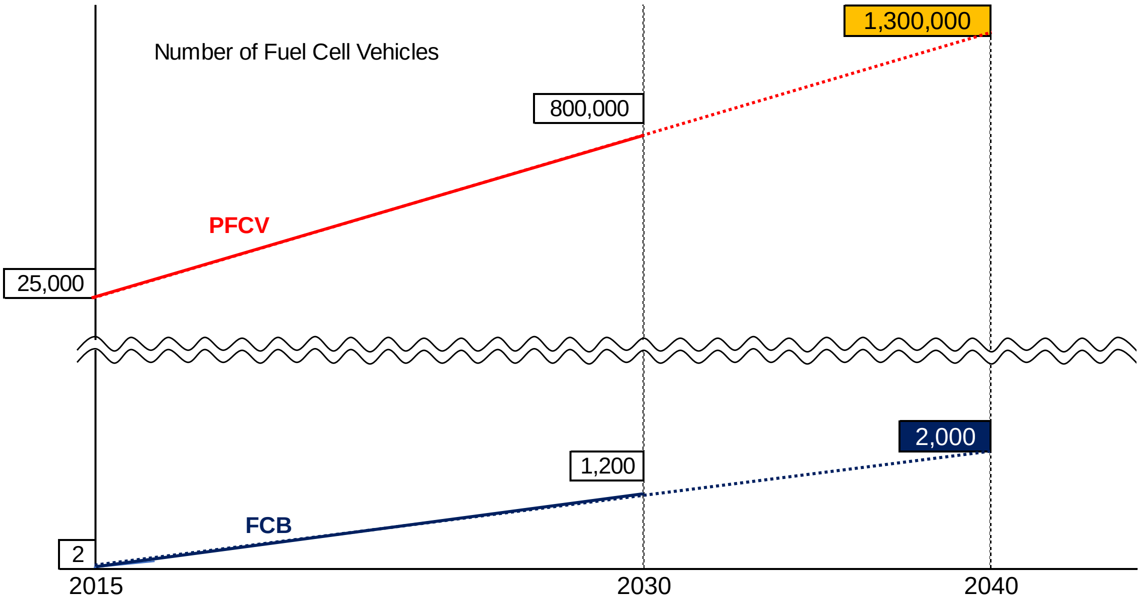
As described in section 3.1, passenger fuel cell vehicles (PFCVs), fuel cell buses (FCBs) and fuel cell trains (FCTs) are studied. For PFCVs and FCBs, Japan's scenario was set first and then applied to OECD countries and non-OECD countries differently.

4.1. Assumption and Scenario for Transport

4.1.1 Number of PFCVs and FCBs in Japan

The study assumed that Japan's Basic Hydrogen Strategy, i.e. 800,000 PFCVs and 1,200 FCBs by 2030, will be accomplished. The numbers of PFCVs and FCBs in 2040 are estimated as a straight-line extrapolation of the trend until 2030, i.e. 1,300,000 and 2,000, respectively, as shown in Figure 3.4.

Figure 3.4 Estimation of Number of PFCVs and FCBs in Japan (2040)



FCB = fuel cell bus, PFCV = passenger fuel cell vehicles.
Source: Author.

4.1.2 PFCV Scenario

First, Japan's PFCV hydrogen demand potential through 2040 is assumed, as shown in Table 3.8. Of all Japan's gasoline-powered passenger vehicles in 2040, 2% are assumed to be converted to hydrogen.[2]

Table 3.8 Basic PFCV Scenario in Japan (2040)

(a)	Number of vehicles in 2040	72 million	ERIA outlook
(b)	Estimated share of passenger vehicles in 2040	79%	same as 2016
(c)	Estimated number of passenger vehicles in 2040	57 million	(a)*(b)
(d)	Number of PFCV in 2040	1.3 million	Figure 3.4
(e)	Estimated share of PFCV in 2040	2%	(d)/(c)

ERIA = Economic Research Institute of ASEAN and East Asia, PFCV = passenger fuel cell vehicles.
Source: Author.

[2] Passenger vehicles are assumed to be gasoline-powered.

Next, other countries' scenarios are assumed, i.e. that OECD countries' PFCV penetration rate will be the same as Japan's, while the rate will be halved in non-OECD countries. Table 3.9 shows the scenarios for the share of PFCV in 2040.

Table 3.9 PFCV Scenarios

Scenario	Japan and other OECD	Non-OECD
Scenario 1	(Japan's basic scenario) 2%	1%
Scenario 2	10%	5%
Scenario 3	20%	10%

OECD = Organisation for Economic Co-operation and Development, PFCV = passenger fuel cell vehicle.
Source: Author.

To calculate PFCV hydrogen demand, the fuel mileage difference between gasoline vehicles and hydrogen vehicles should be considered. For the TOYOTA CROWN (gasoline) and the TOYOTA MIRAI (hydrogen) (see section 3.5.4), the mileage of hydrogen vehicles is 2.7 times better than that of gasoline vehicles;[3] thus, PFCV hydrogen demand is calculated as indicated below:

PFCV hydrogen demand (toe) = Replaced gasoline demand (toe)/2.7

4.1.3 FCB Scenario

First, Japan's FCB hydrogen demand potential is assumed, with Table 3.10 showing its basic 2040 FCB scenario. In Japan, 0.02% of diesel consumption for transport in 2040 is assumed to be converted to hydrogen.

[3] Crown: 10,929 km/toe, MIRAI: 29,466 km/toe.

Table 3.10 Basic FCB Scenario in Japan (2040)

(a)	Diesel consumption for Transport in 2040	22.7 Mtoe	ERIA Outlook
(b)	Assumed travel distance of bus	41,000 km/Bus/Year	*1
(c)	Estimated fuel economy of diesel engine bus	4 km/Litre	*2
(d)	Number of FCBs in 2040	2,000	Figure 3.4
(e)	Replaced diesel consumption by FCB	0.02 Mtoe	(b)/(c)*(d)
(f)	Share of FCB fuel consumption	0.02%	(e)/(a)

FCB = fuel cell bus, Mtoe = million tonnes of oil equivalent.

Note: *1 Fixed route buses, calculated by the example of Yokohama City Bus (2002). FCBs are assumed to be fixed route buses.

*2 Ministry of Land, Infrastructure, Transport and Tourism

Source: Author.

Next, other countries' scenario is assumed, with Japan's scenario applied directly to OECD countries and half applied to non-OECD countries. Table 3.11 shows the FCB scenarios, which consist of the share of hydrogen in diesel consumption for transport in 2040.

Table 3.11 FCB Scenarios

Scenario	Japan and other OECD	Non-OECD
Scenario 1	0.05%	0.025%
Scenario 2	(Japan's basic scenario) 0.1%	0.05%
Scenario 3	0.2%	0.1%

Source: Author.

Due to a lack of information, FCB fuel mileage is assumed to be the same as for a conventional diesel-powered bus.

4.1.4 Assumption of Diesel Consumption for Rail Transport in 2040

Table 3.12 shows the assumed diesel consumption for rail transport in 2040, when a percentage of the diesel locomotive fleet will have been converted to FCTs. When the country data for actual rail transport diesel consumption are not available, the share is assumed to become 10% in 2040.

Table 3.12 Assumed Share of Diesel Consumption for Rail Transport in 2040

Country	2016	2040
Brunei Darussalam	-	-
Cambodia	19%	19%
Indonesia	N/A	10%
Lao PDR	N/A	10%
Malaysia	N/A	10%
Myanmar	61%	61%
Philippines	N/A	10%
Singapore	-	-
Thailand	1%	1%
Viet Nam	N/A	10%
Australia	8%	8%
China	3%	3%
India	5%	5%
Japan	1%	1%
Republic of Korea	1%	1%
New Zealand	2%	2%

Lao PDR = Lao People's Democratic Republic.
Source: 2016 data; World Energy Balances 2018 database, International Energy Agency.

For rail transport, 10% of diesel fuel consumption is assumed to be converted to hydrogen as the basic scenario. Table 3.13 shows the FCT scenarios, which consist of the share of hydrogen in diesel consumption for rail transport in 2040.

Table 3.13 FCT Scenarios

Scenario	EAS Countries
Scenario 1	5%
Scenario 2	(basic scenario) 10%
Scenario 3	20%

EAS = East Asia Summit, FCT = fuel cell train.
Source: Author.

To calculate FCT hydrogen demand, the fuel mileage difference between diesel and hydrogen locomotives should be considered. However, due to lack of necessary information, FCT fuel mileage is assumed to be same as that for conventional diesel locomotives.

4.2. Hydrogen Demand Potential for Transport Sector

4.2.1. Hydrogen Demand Potential for PFCV

Table 3.14 shows the PFCV hydrogen demand potential by country in 2040. The calculation method is described in Appendix 3.4.

Table 3.14 PFCV Hydrogen Demand Potential for 2040(in Mtoe)

Country	Scenario 1	Scenario 2	Scenario 3
Brunei Darussalam	0.0	0.0	0.0
Cambodia	0.0	0.0	0.1
Indonesia	0.3	1.4	2.7
Lao PDR	0.0	0.0	0.0
Malaysia	0.1	0.6	1.1
Myanmar	0.0	0.2	0.4
Philippines	0.0	0.1	0.2
Singapore	0.0	0.0	0.0
Thailand	0.0	0.2	0.3
Viet Nam	0.0	0.2	0.5
ASEAN	**0.5**	**2.7**	**5.4**
Australia	0.1	0.5	1.0
China	0.9	4.6	9.3
India	0.5	2.7	5.4
Japan	0.2	1.0	1.9
Republic of Korea	0.1	0.3	0.6
New Zealand	0.0	0.1	0.2
Other than ASEAN	**1.8**	**9.2**	**18.4**
Total	**2.4**	**11.9**	**23.8**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic, Mtoe = million tonnes of oil equivalent, PFCV = passenger fuel cell vehicles.
Source: Author.

4.2.2. Hydrogen Demand Potential for FCB

Table 3.15 shows the FCB hydrogen demand potential by country in 2040. The calculation method is described in Appendix 3.5.

Table 3.15 FCB Hydrogen Demand Potential in 2040 (in Mtoe)

Country	Scenario 1	Scenario 2	Scenario 3
Brunei Darussalam	0.00	0.00	0.00
Cambodia	0.00	0.00	0.00
Indonesia	0.02	0.04	0.08
Lao PDR	0.00	0.00	0.00
Malaysia	0.00	0.01	0.02
Myanmar	0.00	0.00	0.00
Philippines	0.00	0.01	0.01
Singapore	0.00	0.00	0.00
Thailand	0.00	0.01	0.02
Viet Nam	0.01	0.01	0.02
ASEAN	**0.04**	**0.08**	**0.16**
Australia	0.00	0.01	0.01
China	0.05	0.09	0.18
India	0.03	0.06	0.13
Japan	0.01	0.02	0.03
Republic of Korea	0.00	0.01	0.02
New Zealand	0.00	0.00	0.00
Other than ASEAN	**0.09**	**0.18**	**0.37**
Total	**0.13**	**0.27**	**0.53**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic, FCB = fuel cell bus.

Source: Author.

4.2.3 Hydrogen Demand Potential for FCT

Table 3.16 shows the FCT hydrogen demand potential by country in 2040. The calculation method is described in Appendix 3.6.

Table 3.16 FCT Hydrogen Demand Potential for 2040 (in Mtoe)

Country	Scenario 1	Scenario 2	Scenario 3
Brunei Darussalam	-	-	-
Cambodia	0.02	0.04	0.08
Indonesia	0.42	0.85	1.70
Lao PDR	0.01	0.01	0.02
Malaysia	0.10	0.19	0.39
Myanmar	0.03	0.05	0.10
Philippines	0.06	0.12	0.25
Singapore	-	-	-
Thailand	0.01	0.01	0.02
Viet Nam	0.11	0.23	0.46
ASEAN	**0.75**	**1.51**	**3.02**
Australia	0.05	0.10	0.20
China	0.24	0.47	0.94
India	0.31	0.61	1.22
Japan	0.01	0.01	0.02
Republic of Korea	0.00	0.01	0.02
New Zealand	0.00	0.00	0.01
Other than ASEAN	**0.60**	**1.21**	**2.42**
Total	**1.36**	**2.72**	**5.44**

ASEAN = Association of Southeast Asian Nations, FCT = fuel cell train, Lao PDR = Lao People's Democratic Republic, Mtoe = million tonnes of oil equivalent.
Source: Author.

4.2.4 Hydrogen Demand Potential for Transport Sector (Summary)

Table 3.17 summarises the hydrogen demand potential for the transport sector by country in 2040.

Table 3.17 Summary of Transport Sector Hydrogen Demand Potential for 2040 (in Mtoe)

Country	Scenario 1 PFCV	Scenario 1 FCB	Scenario 1 FCT	Scenario 1 Total	Scenario 2 PFCV	Scenario 2 FCB	Scenario 2 FCT	Scenario 2 Total	Scenario 3 PFCV	Scenario 3 FCB	Scenario 3 FCT	Scenario 3 Total
Brunei Darussalam	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cambodia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1
Indonesia	0.3	0.0	0.4	0.7	1.4	0.0	0.8	2.3	2.7	0.1	1.7	4.5
Lao PDR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malaysia	0.1	0.0	0.1	0.2	0.6	0.0	0.2	0.8	1.1	0.0	0.4	1.5
Myanmar	0.0	0.0	0.0	0.1	0.2	0.0	0.1	0.3	0.4	0.0	0.1	0.5
Philippines	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.2	0.2	0.0	0.2	0.5
Singapore	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thailand	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.3	0.0	0.0	0.4
Viet Nam	0.0	0.0	0.1	0.2	0.2	0.0	0.2	0.5	0.5	0.0	0.5	1.0
ASEAN	**0.5**	**0.0**	**0.8**	**1.3**	**2.7**	**0.1**	**1.5**	**4.3**	**5.4**	**0.2**	**3.0**	**8.6**
Australia	0.1	0.0	0.1	0.1	0.5	0.0	0.1	0.6	1.0	0.0	0.2	1.2
China	0.9	0.0	0.2	1.2	4.6	0.1	0.5	5.2	9.3	0.2	0.9	10.4
India	0.5	0.0	0.3	0.9	2.7	0.1	0.6	3.4	5.4	0.1	1.2	6.8
Japan	0.2	0.0	0.0	0.2	1.0	0.0	0.0	1.0	1.9	0.0	0.0	2.0
Republic of Korea	0.1	0.0	0.0	0.1	0.3	0.0	0.0	0.3	0.6	0.0	0.0	0.7
New Zealand	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.2	0.0	0.0	0.2
Other than ASEAN	**1.8**	**0.1**	**0.6**	**2.5**	**9.2**	**0.2**	**1.2**	**10.6**	**18.4**	**0.4**	**2.4**	**21.2**
Total	**2.4**	**0.1**	**1.4**	**3.9**	**11.9**	**0.3**	**2.7**	**14.9**	**23.8**	**0.5**	**5.4**	**29.8**

ASEAN = Association of Southeast Asian Nations, FCB = fuel cell bus, FCT = fuel cell train, Lao PDR = Lao People's Democratic Republic, Mtoe = million tonnes of oil equivalent, PFCV = passenger fuel cell vehicle.
Source: Author.

4.3. Summary of Hydrogen Demand Potential

4.3.1. Summary of Scenarios

Table 3.18 summarises the scenarios.

Table 3.18 Summary of Scenarios

Sector	Fuel		Scenario 1	Scenario 2	Scenario 3
			H_2 concentration of mixed fuel		
Electricity generation	Coal	20% of new coal-fired electricity generation will be converted to natural gas and H_2 mixed fuel-fired generation	H_2: 10% Nat gas: 90%	H_2: 20% Nat gas: 80%	H_2: 30% Nat gas: 70%
	Natural gas	20% of new natural gas-fired electricity generation will be converted to natural gas and H_2 mixed fuel-fired generation			
Industry	Natural gas	20% of natural gas consumption for industrial purpose will be replaced by natural gas and H_2 mixed fuel			
			Share of H_2/ gasoline for passenger car		
Transport	Gasoline	Passenger Fuel Cell Vehicle: Gasoline demand will be converted to H_2	OECD H_2: 2.0% Gasoline: 98% Non-OECD H_2: 1.0% Gasoline: 99%	OECD H_2: 10% Gasoline: 90% Non-OECD H_2: 5% Gasoline: 95%	OECD H_2: 20% Gasoline: 80% Non-OECD H_2: 10% Gasoline: 90%
			Share of H_2/ diesel for bus		
	Diesel	Fuel Cell Bus: Diesel demand will be converted to H_2	Japan H_2: 0.05% Gasoline: 99.95% Other countries H_2: 0.025% Gasoline: 99.975%	Japan H_2: 0.1% Gasoline: 99.9% Other countries H_2: 0.05% Gasoline: 99.95%	Japan H_2: 0.2% Gasoline: 99.8% Other countries H_2: 0.1% Gasoline: 99.9%
			Share of H_2/ diesel for rail transport)		
	Diesel	Fuel Cell Train: Diesel consumption for rail transport will be converted to H_2	H_2: 5% Diesel: 95%	H_2: 10% Diesel: 90%	H_2: 20% Diesel: 80%

Source: Author.

4.3.2 Summary of Hydrogen Demand Potential in ASEAN and EAS

Table 3.19 shows hydrogen demand potential by country in 2040. The potential of ASEAN is projected as 6.6 Mtoe in Scenario 1, 14.9 Mtoe in Scenario 2, and 24.4 Mtoe in Scenario 3. The potential of the EAS region is projected as 28.9 Mtoe in Scenario 1, 64.9 Mtoe in Scenario 2, and 104.7 Mtoe in Scenario 3.

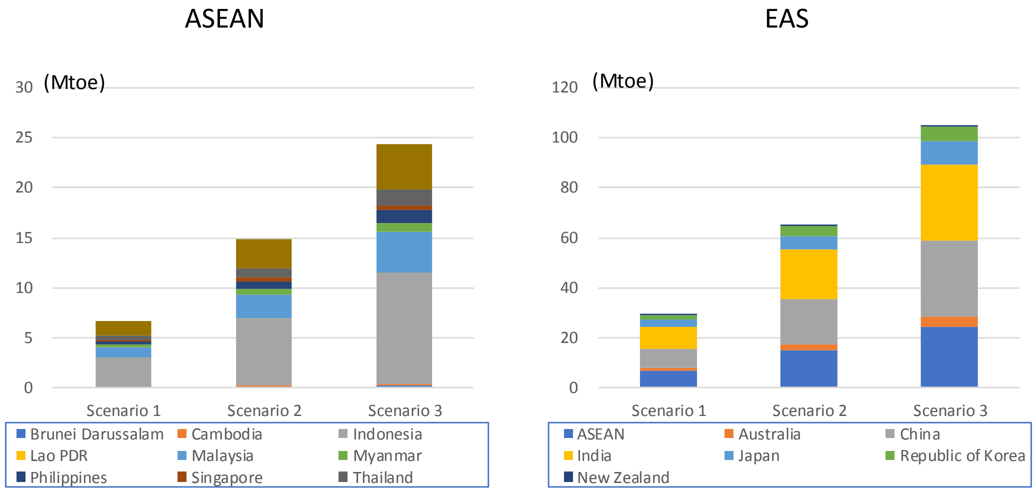
Table 3.19 Summary of Hydrogen Demand Potential in 2040 (in Mtoe)

	Scenario 1				Scenario 2				Scenario 3			
Country	Electricity	Industry	Transport	Total	Electricity	Industry	Transport	Total	Electricity	Industry	Transport	Total
Brunei Darussalam	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.1
Cambodia	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.2	0.1	0.0	0.1	0.3
Indonesia	1.9	0.3	0.7	2.9	0.0	0.0	2.3	6.6	5.8	0.8	4.5	11.1
Lao PDR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malaysia	0.6	0.3	0.2	1.0	1.1	0.5	0.8	2.4	1.7	0.8	1.5	4.0
Myanmar	0.1	0.0	0.1	0.2	0.2	0.1	0.3	0.5	0.3	0.1	0.5	0.9
Philippines	0.3	0.0	0.1	0.4	0.6	0.0	0.2	0.9	0.9	0.0	0.5	1.4
Singapore	0.1	0.0	0.0	0.1	0.2	0.1	0.0	0.3	0.3	0.1	0.0	0.5
Thailand	0.2	0.2	0.0	0.5	0.5	0.4	0.2	1.0	0.7	0.6	0.4	1.6
Viet Nam	1.1	0.1	0.2	1.4	2.1	0.3	0.5	2.9	3.2	0.4	1.0	4.6
ASEAN	4.4	0.9	1.3	6.6	8.7	1.8	4.3	14.9	13.1	2.8	8.6	24.4
Australia	0.7	0.2	0.1	1.0	1.4	0.3	0.6	2.3	2.1	0.5	1.2	3.8
China	4.8	1.8	1.2	7.9	9.7	3.6	5.2	18.5	14.5	5.4	10.4	30.3
India	7.4	0.7	0.9	9.0	14.8	1.3	3.4	19.5	22.3	2.0	6.8	31.0
Japan	2.0	0.3	0.2	2.5	4.0	0.6	1.0	5.6	6.0	0.9	2.0	8.9
Republic of Korea	1.5	0.2	0.1	1.8	3.1	0.4	0.3	3.9	4.6	0.7	0.7	6.0
New Zealand	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.2	0.1	0.1	0.2	0.3
Other than ASEAN	16.5	3.2	2.5	22.2	33.1	6.4	10.6	50.0	49.6	9.5	21.2	80.3
Total	20.9	4.1	3.9	28.9	41.8	8.2	14.9	64.9	62.7	12.3	29.8	104.7

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People’s Democratic Republic, Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure 3.5 shows the hydrogen demand potential by country in 2040. Indonesia has the largest hydrogen demand potential amongst ASEAN member countries, followed by Malaysia and Viet Nam. China has the largest hydrogen demand potential in the EAS region, followed by India and ASEAN total.

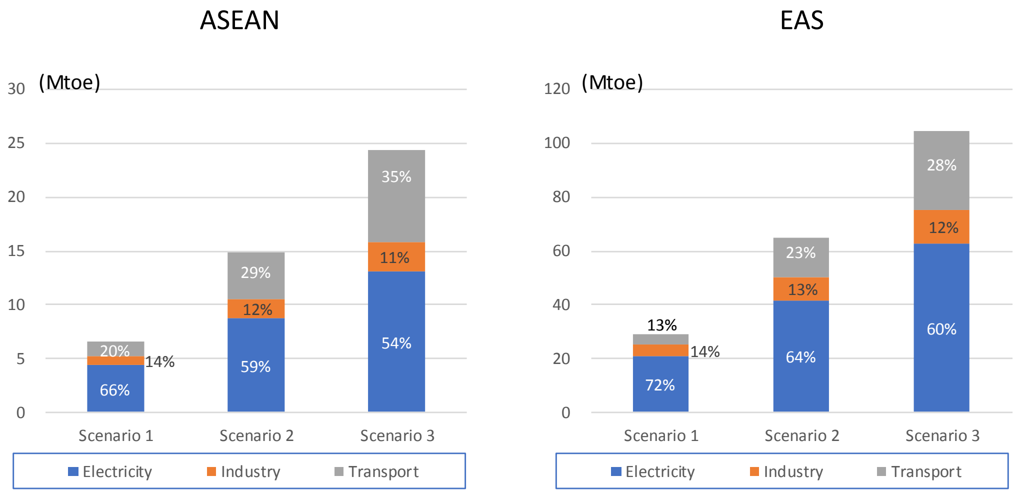
Figure 3.5 Hydrogen Demand Potential by Country



ASEAN = Association of Southeast Asian Nations, EAS = East Asia Summit, Lao PDR = Lao People's Democratic Republic, Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure 3.6 shows the hydrogen demand potential by sector in 2040. Electricity generation has the largest hydrogen demand potential in all scenarios in both ASEAN and the EAS region. Country analysis is shown in Appendix 3.7.

Figure 3.6 Hydrogen Demand Potential by Sector



ASEAN = Association of Southeast Asian Nations, EAS = East Asia Summit, Mtoe = million tonnes of oil equivalent.
Source: Author.

5.Competitive Hydrogen Prices from a Demand-Side Point of View

In this section, the price competitiveness of hydrogen compared with conventional fuel is calculated by sector. Two cases of prices, without CO_2 premium and with CO_2 premium, are estimated. Because the comparison is made only for hydrogen's potential as a fuel, it does not calculate end-use cost difference, e.g. capital expenditure to build a plant and its operating cost.

Electricity generation sector: Compare with import prices of fossil fuel

Industry sector: Compare with current natural gas retail price for Industry in Japan

Transport sector: Compare with current gasoline retail price in Indonesia and Japan

5.1. Basic Assumption and Conversion Factor for Calculation

Table 3.20 shows the assumption of prices.

Table 3.20 Assumption of Prices

Sector	Fuel	Price	Source
Electricity generation	Imported Coal	\$10.0/ MMbtu (\$397/ toe)	New Policy Scenario, WEO 2018, IEA Average of Japan and Coastal China
	Imported Natural gas	\$92/ tonne (\$150/ toe)	New Policy Scenario, WEO 2018, IEA Average of China and Japan
Industry	Natural gas for Industry	\$547.4/ toe	Energy Prices and Taxes Q3 2018, IEA 2017. Japan
Transport	Retail price of Gasoline (Indonesia)	\$84.39/ BOE (\$0.531/ L)	Handbook of Energy & Economic Statistics of Indonesia 2017
	Retail price of Gasoline (Japan)	\$1.19/ L (tax incl.) \$0.597/ L (tax excl.)	2017 Japan. Energy Prices and Taxes Q32018, IEA The share of tax: 49.8%
All sectors	CO_2	\$41/ tonne	2040 (2017 price), New Policy Scenario, WEO 2018, IEA Average of China, European Union and Republic of Korea

BOE = barrel oil equivalent, IEA = International Energy Agency, MMbtu = millions of BTUs, toe = tonnes of oil equivalent, WEO = World Energy Outlook.
Source: Author.

Table 3.21 shows other assumptions and conversion factors.

Table 3.21 Other Assumptions and Conversion Factors

Carbon content	Coal: 25.8 kg-C/GJ (=3.961 tonne-CO_2/toe-input) Natural gas: 15.3 kg-C/GJ (=2.349 tonne-CO_2/toe-input) Gasoline: 18.9 kg-C/GJ (=2.902 tonne-CO_2/toe) (=2.269 tonne-CO_2/KL)	Source: CO_2 Emissions from Fuel Combustion 2018, IEA
NCV	Other Bituminous Coal (Australian export coal) 0.6138 toe/tonne	Source: World Energy Balances 2018 database, IEA
H_2 specification	Gas density: 0.0835 kg/m^3 NCV: 10,780 kJ/m^3 = 2,575 kcal/m^3 = 30,834 kcal/kg = 3,884 m^3/toe	Source: Iwatani Corporation
Thermal efficiency (Electricity generation)	Coal: 55% Natural gas: 63% H_2: 63%	Source: High Efficiency of Thermal Power, November 2017, ANRE, METI
Conversion factor	1GJ = 0.02388 toe 1cal = 4.187 J 1Gcal = 0.1 toe 1MWh = 0.086 toe 1MMbtu = 0.0252 toe	-

ANRE = Agency for Natural Resources and Energy, IEA = International Energy Association, METI = Ministry of Economy, Trade, and Industry, Japan, NCV = net calorific value, toe = tonnes of oil equivalent.
Source: Author.

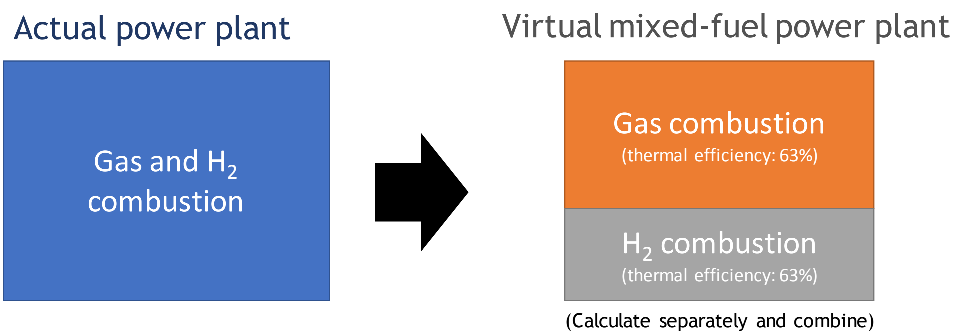
5.2. Estimated Competitive Hydrogen Prices for Electricity Generation

In this study, estimated hydrogen prices for electricity generation are defined as follows:

Coal (or natural gas) consumption * unit price = Hydrogen consumption * competitive price

To calculate competitive hydrogen prices with or without CO_2 premium, natural gas and hydrogen are separately calculated in a virtual mixed fuel, as shown in Figure 3.7.

Figure 3.7 Virtual Mixed-Fuel Power Plant



Source: Author.

Table 3.22 shows the competitive price of hydrogen for electricity generation.

Table 3.22 Estimated Competitive Price of Hydrogen for Electricity Generation (in US dollars)

Without CO_2 Premium		With CO_2 Premium	
vs. Coal	vs. Natural gas	vs. Coal	vs. Natural gas
($/toe)	($/toe)	($/toe)	($/toe)
172[*1]	397	274	458
($/m^3)	($/m^3)	($/m^3)	($/m^3)
0.044	0.102	0.071	0.118

toe = tonnes of oil equivalent.
Note: *1: Due to difference of thermal efficiency, coal requires more energy to generate the same amount of electricity as compared to natural gas.
Source: Author.

5.3 Estimated Competitive Hydrogen Prices for Industry

Table 3.23 shows the estimated competitive hydrogen prices for industry.

Table 3.23 Estimated Competitive Price of Hydrogen for Industry(in US dollars)

Without CO_2 Premium vs. Natural gas	With CO_2 Premium vs. Natural gas
($/toe) 547.4	($/toe) 643.7
($/$m^3$) 0.141	($/$m^3$) 0.166

toe = tonnes of oil equivalent.
Source: Author.

5.4. Estimated Competitive Hydrogen Prices for Transport

In this section, the competitive hydrogen price for PFCVs is compared with the gasoline price for an internal combustion engine car. The TOYOTA MIRAI is selected as a PFCV and the TOYOTA CROWN is selected as the internal combustion engine vehicle because dimensions are similar.

Table 3.24 shows the comparison between TOYOTA CROWN and TOYOTA MIRAI.

Table 3.24 Comparison between TOYOTA CROWN and TOYOTA MIRAI

	CROWN	MIRAI
Appearance		
Dimensions (cm) Length	4,910	4,890
Width	1,800	1,815
Height	1,455	1,535
Weight (kg)	1,590–1,650	1,850
Displacement	2,000 cc	
Fuel mileage (JC08 mode)	12.8 km/litre *1	7.59 km/ m^3 *2
Fuel consumption per 100 km	7.81 litre	13.18 m^3

Note: *1 Source: TOYOTA MOTOR CORPORATION
*2 MIRAI's fuel tank capacity: 122.4 L, pressure: 70 Mpa => 85.68 m^3-H_2/full load
MIRAI can run 650 km/ full load of H_2.

Table 3.25 shows the expense of driving the TOYOTA CROWN 100 km, assuming gasoline consumption of 7.81 litre in JC08 mode, with gasoline prices in Japan and Indonesia being $0.597/litre and $0.531/litre, respectively.

Table 3.25 Expense of 100 km Driving of TOYOTA CROWN (In US dollars)

	Japan	Indonesia
Expense	$4.67	$4.15

Source: Author.

TOYOTA MIRAI consumes 13.18m^3 of hydrogen for 100 km driving. Table 3.26 shows the competitive price of hydrogen for PFCVs in Japan and Indonesia against the expense of 100 km driving of TOYOTA CROWN.

Table 3.26 Estimated Competitive Price of Hydrogen for PFCVs (In US dollars)

	Japan	Indonesia
Without CO_2 Premium	$0.354/ m^3 ($1,375/ toe)	$0.315/m^3 ($1,222/ toe)
With CO_2 Premium	$0.417/ m^3 ($1,621/ toe)	$0.378/m^3 ($1,467/ toe)

toe = tonnes of oil equivalent.
Source: Author.

5.5. Estimated Competitive Hydrogen Prices (Summary)

Table 3.27 shows the summary of estimated competitive price of hydrogen. Hydrogen costs should be reduced to enable market penetration.

Table 3.27 Estimated Competitive Hydrogen Prices(In US dollars)

Sector	Fuel	Without CO_2 premium ($/toe)	Without CO_2 premium ($/m^3)	With CO_2 premium ($/toe)	With CO_2 premium ($/m^3)
Electricity	Coal	172	0.044	274	0.071
	Natural gas	397	0.102	458	0.118
Industry	Natural gas	547	0.141	644	0.166
Transport	Gasoline				
	Japan	1,375	0.354	1,589	0.409
	Indonesia	1,222	0.315	1,436	0.370

toe = tonnes of oil equivalent.
Note: Capital expenditure and operating expenditure (except fuel) of end-use item differences between conventional energy and hydrogen are not considered.
Source: Author.

In this study, import price and CO_2 price draw on 2040 projections in the WEO 2018 New Policy Scenario. WEO 2018 offered the Sustainable Development Scenario in addition to the New Policy Scenario, which assumes stronger climate actions and a higher CO_2 cost of $133/tonne that could increase price competitiveness of clean hydrogen. Tables 3.28 and 3.29 summarise the estimated competitive hydrogen prices, drawing on the Sustainable Development Scenario as an alternative case.

Because of a resulting increased CO_2 cost environment, stronger climate policies can support expanded use of clean hydrogen.

Table 3.28 Estimated Competitive Hydrogen Prices (Sustainable Development Scenario)
(In US dollars)

Sector	Fuel	Without CO_2 premium ($/toe)	Without CO_2 premium ($/m^3)	With CO_2 premium ($/toe)	With CO_2 premium ($/m^3)
Electricity	Coal	140	0.036	472	0.121
	Natural gas	345	0.089	542	0.140
Industry	Natural gas	547	0.141	860	0.221
Transport	Gasoline				
	Japan	1,375	0.354	2,070	0.533
	Indonesia	1,222	0.315	1,917	0.493

toe = tonnes of oil equivalent.
Note: Capital expenditure and operating expenditure (except fuel) of end-use item differences between conventional energy and hydrogen are not considered.
Source: Author.

Table 3.29 Assumptions (Sustainable Development Scenario) (In US dollars)

Sector	Fuel	Price
Import price	Coal	$75/tonne ($150/toe)
	Natural gas	$8.70/MMbtu ($397/toe)
CO_2 price	CO_2	$133/tonne-$CO_2$
For Industry	Natural gas	$547.40/toe
Transport	Gasoline	Japan: $0.597/litre Indonesia: $0.531/litre

Thermal efficiency	
Coal	55%
Natural gas	63%
H_2	63%

toe = tonnes of oil equivalent.
Note: Letters in red = Sustainable Development Scenario.
Source: Author.

6. Estimated Reduction of Fossil Fuel Consumption and CO_2 Emissions

This section analyses how introducing hydrogen into the energy mix reduces fossil fuel consumption and, hence, CO_2 emissions. The calculation method and sectoral analysis are presented in Appendices 3.8 to 3.13.

6.1. Estimated Reduction of Fossil Fuel Consumption

Table 3.30 shows the projected energy replaced by hydrogen in 2040. Natural gas demand will increase in many countries because 20% of coal consumption will be replaced by natural gas and hydrogen mixed fuel in electricity generation.

Table 3.30 Replaced Energy by Hydrogen in 2040

Country	Scenario 1				Scenario 2				Scenario 3			
	Coal (Mln tonnes)	Nat gas (Bcm)	Gasoline (000 tonnes)	Diesel (000 tonnes)	Coal (Mln tonnes)	Nat gas (Bcm)	Gasoline (000 tonnes)	Diesel (000 tonnes)	Coal (Mln tonnes)	Nat gas (Bcm)	Gasoline (000 tonnes)	Diesel (000 tonnes)
Brunei Darussalam	-0.1	0.1	-6	-0	-0.1	0.1	-30	-0	-0.1	0.0	-59	-0
Cambodia	-0.3	0.3	-13	-20	-0.3	0.2	-66	-41	-0.3	0.2	-132	-82
Indonesia	-15.4	13.4	-691	-437	-15.4	11.6	-3,455	-875	-15.4	9.8	-6,909	-1,750
Lao PDR			-2	-6			-12	-13			-24	-26
Malaysia	-2.3	1.5	-281	-100	-2.3	1.0	-1,403	-200	-2.3	0.5	-2,806	-399
Myanmar	-0.7	0.6	-107	-25	-0.7	0.5	-536	-50	-0.7	0.4	-1,072	-100
Philippines	-1.9	1.6	-59	-64	-1.9	1.4	-295	-128	-1.9	1.2	-590	-257
Singapore	-0.0	-0.1	-8	-0	-0.0	-0.2	-42	-1	-0.0	-0.2	-84	-1
Thailand	-1.1	0.7	-84	-11	-1.1	0.4	-418	-21	-1.1	0.1	-837	-42
Viet Nam	-9.1	8.0	-123	-118	-9.1	7.0	-615	-235	-9.1	5.9	-1,230	-470
ASEAN	-31.0	26.1	-1,374	-782	-31.0	22.0	-6,871	-1,564	-31.0	17.9	-13,743	-3,128
Australia	-4.0	3.1	-245	-52	-4.0	2.5	-1,225	-105	-4.0	2.0	-2,450	-209
China	-21.9	15.3	-2,349	-276	-21.9	11.2	-11,745	-553	-21.9	7.1	-23,490	-1,106
India	-71.7	64.6	-1,369	-332	-71.7	56.6	-6,844	-664	-71.7	48.6	-13,689	-1,327
Japan	-9.5	7.2	-489	-13	-9.5	6.0	-2,443	-26	-9.5	4.7	-4,885	-51
Republic of Korea	-8.6	7.0	-163	-9	-8.6	5.9	-814	-17	-8.6	4.8	-1,629	-34
New Zealand	0.0	-0.1	-42	-3	0.0	-0.1	-210	-5	0.0	-0.1	-419	-10
Other than ASEAN	-115.6	97.3	-4,656	-684	-115.6	82.2	-23,281	-1,369	-115.6	67.0	-46,562	-2,737
Total	-146.6	123.4	-6,031	-1,466	-146.6	104.2	-30,153	-2,933	-146.6	84.9	-60,305	-5,866

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic.
Source: Author.

6.2. Estimated CO_2 Emission Reduction

Table 3.31 shows the total CO_2 emissions from fuel combustion by scenario in ASEAN and the EAS region. CO_2 emissions can be reduced by up to 2.7% depending on the scenario, compared to the ERIA benchmark outlook.

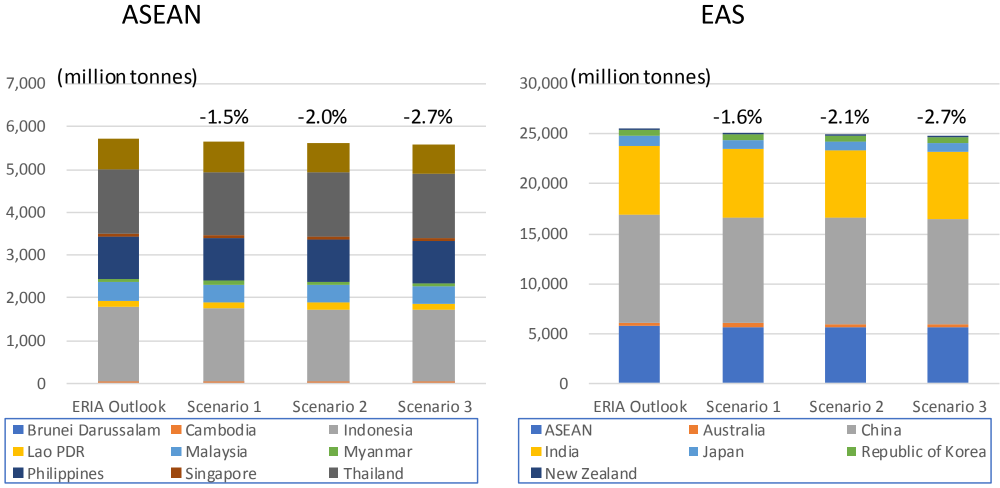
Table 3.31 Total CO_2 Emissions from Fuel Combustion in 2040

	Total CO_2 emissions (million tonnes)				CO_2 emission reduction		
	ERIA Outlook	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Brunei Darussalam	16.0	15.6	15.5	15.3	-2.0%	-3.1%	-4.2%
Cambodia	27.9	27.0	26.6	26.2	-3.1%	-4.4%	-6.0%
Indonesia	1,745.9	1,704.3	1,689.2	1,670.6	-2.4%	-3.2%	-4.3%
Lao PDR	150.1	150.1	150.0	150.0	0.0%	-0.1%	-0.1%
Malaysia	426.3	418.3	412.6	405.7	-1.9%	-3.2%	-4.8%
Myanmar	85.7	83.4	81.7	79.6	-2.7%	-4.7%	-7.1%
Philippines	996.0	990.8	989.2	987.1	-0.5%	-0.7%	-0.9%
Singapore	62.9	62.5	62.1	61.6	-0.6%	-1.3%	-2.1%
Thailand	1,503.8	1,500.2	1,498.1	1,495.8	-0.2%	-0.4%	-0.5%
Viet Nam	715.8	692.8	688.1	682.7	-3.2%	-3.9%	-4.6%
ASEAN	**5,730.4**	**5,645.1**	**5,613.2**	**5,574.6**	**-1.5%**	**-2.0%**	**-2.7%**
Australia	367.8	356.3	351.1	344.9	-3.1%	-4.5%	-6.2%
China	10,746.7	10,676.3	10,630.8	10,577.1	-0.7%	-1.1%	-1.6%
India	6,943.3	6,766.2	6,729.2	6,687.0	-2.6%	-3.1%	-3.7%
Japan	965.6	938.5	927.0	914.0	-2.8%	-4.0%	-5.3%
Rep. of Korea	670.2	647.1	640.9	634.2	-3.4%	-4.4%	-5.4%
New Zealand	29.1	28.8	28.2	27.4	-0.9%	-3.1%	-5.8%
Other than ASEAN	**19,722.6**	**19,413.3**	**19,307.2**	**19,184.6**	**-1.6%**	**-2.1%**	**-2.7%**
Total	**25,452.9**	**25,058.3**	**24,920.4**	**24,759.2**	**-1.6%**	**-2.1%**	**-2.7%**

ASEAN = Association of Southeast Asian Nations, ERIA = Economic Research Institute of ASEAN and East Asia, Lao PDR = Lao People's Democratic Republic.
Source: Author.

Figure 3.8 shows the total CO_2 emissions from fuel combustion by country. Indonesia has the largest CO_2 emissions reduction potential in ASEAN member countries, while India has the largest CO_2 emissions reduction potential despite being the second-largest emitter in the EAS region. Country-wise analysis is described in Appendix 3.14.

Figure 3.8 Total CO_2 Emissions from Fuel Combustion by Country



ASEAN = Association of Southeast Asian Nations, EAS = East Asia Summit, Lao PDR = Lao People's Democratic Republic.

Source: Author.

Table 3.32 shows the economic impact of CO_2 emissions reduction by country. The economic impact is calculated by multiplying CO_2 emissions reduction amount by the CO_2 price. Other elements are not considered. The price of CO_2 in 2040 is assumed to be $41/tonne-$CO_2$.

In ASEAN, the economic impact of CO_2 emissions reduction is $3.5 billion in Scenario 1, $4.8 billion in Scenario 2, and $6.4 billion in Scenario 3. In the EAS region, the economic impact of CO_2 emissions reduction reaches $16.2 billion in Scenario 1, $21.8 billion in Scenario 2, and $28.4 billion in Scenario 3.

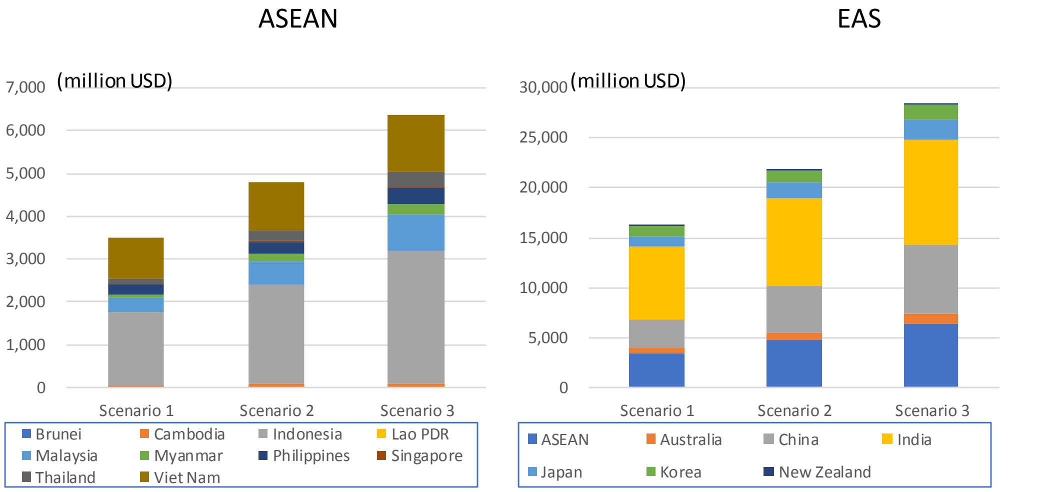
Table 3.32 Economic Impact of CO_2 Emissions Reduction(in million US$)

Country	Scenario 1	Scenario 2	Scenario 3
Brunei Darussalam	13	20	27
Cambodia	36	50	68
Indonesia	1,705	2,324	3,086
Lao PDR	1	3	6
Malaysia	329	563	845
Myanmar	94	164	250
Philippines	212	280	363
Singapore	16	34	53
Thailand	147	231	326
Viet Nam	943	1,136	1,359
ASEAN	**3,497**	**4,803**	**6,385**
Australia	469	684	938
China	2,884	4,751	6,951
India	7,260	8,776	10,508
Japan	1,111	1,581	2,115
Republic of Korea	947	1,200	1,475
New Zealand	11	37	69
Other than ASEAN	**12,682**	**17,030**	**22,056**
Total	**16,179**	**21,833**	**28,442**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic.
Source: Author.

Figure 3.9 shows the economic impact of CO_2 emissions reduction by country. Country-wise analysis is described in Appendix 3.15.

Figure 3.9 Economic Impact of CO_2 Emissions Reduction (ASEAN and EAS)



ASEAN = Association of Southeast Asian Nations, EAS = East Asia Summit, Lao PDR = Lao People's Democratic Republic.
Source: Author.

Appendix 3.1:Useful Information to Estimate Hydrogen Demand Potential

Appendix 3.1.1. Recent technology development for hydrogen utilisation

Table A3.1.1 shows the progress of the main hydrogen utilisation technologies. While electricity generation, which is expected to have substantial hydrogen demand, is still in the demonstration stage, 100% hydrogen-fuelled industrial boilers are already commercialised; however, they are small scale and assumed to operate on industrial by-product hydrogen. It should be noted that Alstom has begun to operate fuel cell trains (FCTs) commercially in Germany.

Table A3.1.1 Recent Hydrogen Utilisation Technology Development

Purpose	Scale	Fuel	H_2 concentration	Company	Announced	NOx level	Status (Target)
Gas turbine	1,600 ℃ 700 MW class	H_2 Natural gas	30%	MHPS	19 Jan 2018	Low	Demonstration Success
Gas turbine	2 MW	NH_3 Natural gas	20%	IHI	18 April 2018	Low	Demonstration Success
Boiler (Power)	Input 10 MW	NH_3 Coal	20%	IHI	28 March 2018	Low	Demonstration Success
Gas engine	0.6 MW	H_2 Natural gas	20%	JST, SIP, AIST, Three Universities	18 May 2018	Low	Demonstration Success
Boiler (Industry)	Small	H_2 (industrial by-product)	100%	Miura, Takasago	23 Jan 2017 -	NA	Already Commercialised
Boiler (Once-Through boiler)	small?	H_2 (industrial by-product)	100%	Kawasaki Thermal engineering	14 May 2018	Low	2019 Commercialisation
FCT		H_2	100%	Alstom	11 July 2018		September 2018 Alstom has started commercial operation of FCTs in Germany

Note: AIST = National Institute of Advanced Industrial Science and Technology, FCT = fuel cell train, JST= Japan Science & Technology Agency, MHPS = Mitsubishi Hitachi Power Systems, SIP = Cross-Ministerial Strategic Innovation Promotion Program, Three Universities = Okayama, Tokyo City, Waseda.

Source: Press Releases.

Appendix 3.1.2 Example for hydrogen demand timeframe

In this section, the timeframe of hydrogen demand, as described in the documents of the Basic

Hydrogen Strategy from Japan's Ministry of Energy, Trade, and Industry (METI), the Australian Renewable Energy Agency, and the International Energy Agency (IEA), is analysed.

Appendix 3.1.2.1 Basic Hydrogen Strategy, Japan

Figure A3.1.1 shows the hydrogen demand timeframe and the scale of hydrogen demand as described in the Basic Hydrogen Strategy (Japan).

Figure A3.1.1 Basic Hydrogen Strategy, Japan

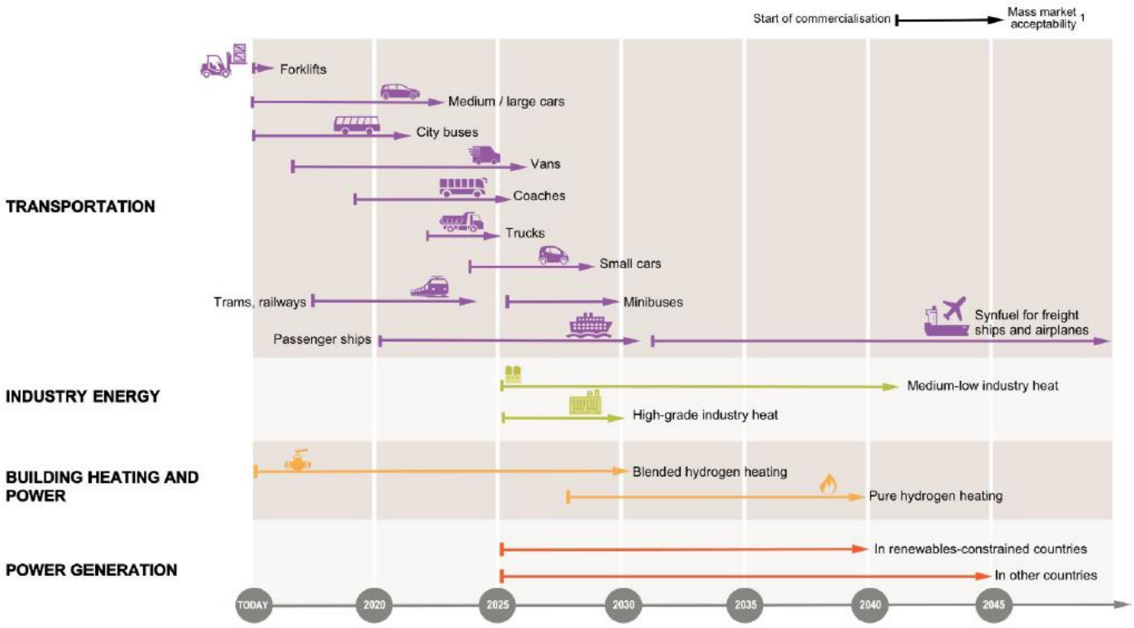
	Present	2030	Future
Electricity Generation	R&D stage	Hydrogen Procurement 300,000 tonnes/y (Equiv. 1 GW)	Hydrogen Procurement 5-10 million tonnes/y (Equiv. 15-30 GW)
Transport (Number of Vehicles)			
FCV	25,000	800,000	Replacing Conventional Gasoline Mobility Introducing Large FCVs Development and Commercialisation of FC Trucks Promote FC small ships
FC Buses	2	1,200	
Forklifts	40	10,000	
Ene-Farm [FC system for Residential] (Number of Unit)	230,000	5,300,000	Replacing Traditional Residential Energy Systems

FC = fuel cell, FCV = fuel cell vehicle.
Source: Basic Hydrogen Strategy (METI, December 2017).

Appendix 3.1.2.2 ARENA, Australia

Figure A3.1.2 shows the hydrogen demand timeframe developed by the Australian Renewable Energy Agency (ARENA), which is optimistic, as Australia has an export target.

Figure A3.1.2 Hydrogen Demand Timeframe by ARENA



ARENA = Australian Renewable Energy Agency.
Source: *Opportunities For Australia From Hydrogen Exports*, August 2018.

Appendix 3.1.2.3 Energy Technology Perspective 2017, IEA

The IEA report on energy technologies outlines how these and other trends as well as technological advances will play out in the next four decades to reshape the global energy sector. Table A3.1.2 describes the Hydrogen Demand in Energy Technology Perspective 2017, IEA.

Table A3.1.2 Hydrogen Demand in Energy Technology Perspective 2017

Sector	Hydrogen Demand
Electricity generation	Hydrogen is not mentioned in ETP 2017.
Industry	In the context of boiler fuel, hydrogen is not mentioned in ETP 2017.
Buildings	Hydrogen is not mentioned in ETP 2017. H12 Hydrogen energy deployment demonstration in Leeds (UK) is introduced. ✓ Hydrogen production with CCS ✓ Cost and complexity to conversion of gas equipment ✓ Depends on UK Government's decision to support CCS
Transport	Hydrogen contributes only a small fraction of the energy demand in the central projections developed in ETP 2017. [Share of FCVs in 2040] ➢ LDV: 1.2% at B2DS, almost zero at RTS ➢ Two- and three-wheelers: zero ➢ Bus and rail: It seems to be almost the same as LDV. ➢ Trucks: It seems to be zero in all scenarios. ➢ Aviation: The potential for aviation to move away from fossil fuels is limited. ➢ International shipping: Hydrogen is considered as additional possibilities to decarbonise international shipping beyond the 2DS and B2DS results.

CCS = carbon capture and storage, ETP = Energy Technology Perspective, FCV = fuel cell vehicle, LDV = light duty vehicles.

Note: RTS: Reference Technology Scenario (= WEO New Policy Scenario);
2DS: 2 °C Scenario (= WEO 450 Scenario);
B2DS: Beyond 2 °C Scenario (CO_2 price: $540/tonne-$CO_2$ in 2060).

Source: Energy Technology Perspective 2017, IEA.

Appendix 3.1.2.4 WEO, IEA

World Energy Outlook 2017 (WEO 2017) IEA describes hydrogen demand from blending with natural gas as follows:

> *[W]ith only minor modifications, the transmission network could cope with up to around 10% hydrogen blended into the natural gas stream.* (Altfeld and Pinchbeck, 2013)
>
> *Many existing natural gas turbines, for example, could only handle around 1% hydrogen injection for performance and safety reasons (although they may be capable of tolerating 5-15% injection with some modifications).*
>
> *Hydrogen injection could displace around 100 bcm of natural gas consumption across the global energy system in 2040.*

World Energy Outlook 2018 (WEO 2018), IEA, latest edition, describes hydrogen demand as follows:

> *To help decarbonise the buildings and industry sectors, hydrogen could be injected into existing gas networks (current regulatory blending limits are relatively low, but up to 20% of hydrogen could be injected into natural gas networks).*

Appendix 3.2 Calculation of Hydrogen Demand Potential for Electricity Generation

Table A3.2.1 Electricity Generation (ERIA Outlook) and Replaced Electricity Generation by Hydrogen

Country	Electricity generation (ERIA Outlook)						20% of new generation			20% of new generation		
	Coal			Natural gas			Coal	Natural gas	Total	Coal	Natural gas	Total
	2015 (TWh)	2040 (TWh)	New (TWh)	2015 (TWh)	2040 (TWh)	New (TWh)	(TWh)	(TWh)	(TWh)	(Mtoe)	(Mtoe)	(Mtoe)
Brunei Darussalam	0.0	3.6	3.6	3.7	14.1	10.3	0.7	2.1	2.8	0.1	0.2	0.2
Cambodia	2.1	13.0	10.9	0.0	7.0	7.0	2.2	1.4	3.6	0.2	0.1	0.3
Indonesia	130.5	681.3	550.8	58.9	220.0	161.1	110.2	32.2	142.4	9.5	2.8	12.2
Lao PDR	2.3	45.2	42.9							0.0	0.0	
Malaysia	63.5	145.8	82.4	70.0	191.4	121.4	16.5	24.3	40.8	1.4	2.1	3.5
Myanmar	0.0	26.6	26.6	6.5	13.7	7.2	5.3	1.4	6.8	0.5	0.1	0.6
Philippines	36.7	105.0	68.3	18.9	55.8	36.9	13.7	7.4	21.0	1.2	0.6	1.8
Singapore	0.6	1.1	0.5	47.9	85.6	37.7	0.1	7.5	7.6	0.0	0.6	0.7
Thailand	32.9	71.8	38.9	117.0	161.0	44.0	7.8	8.8	16.6	0.7	0.8	1.4
Viet Nam	51.0	376.4	325.4	44.9	109.6	64.6	65.1	12.9	78.0	5.6	1.1	6.7
ASEAN	**319.6**	**1,469.9**	**1,150.3**	**367.8**	**858.1**	**490.3**	**221.5**	**98.1**	**319.5**	**19.0**	**8.4**	**27.5**
Australia	158.6	141.4	141.4	52.5	118.6	118.6	28.3	23.7	52.0	2.4	2.0	4.5
China	4,109.0	4,889.0	780.0	145.3	1,139.3	994.0	156.0	198.8	354.8	13.4	17.1	30.5
India	1,041.5	3,598.9	2,557.4	68.1	230.2	162.1	511.5	32.4	543.9	44.0	2.8	46.8
Japan	343.2	337.4	337.4	409.8	390.4	390.4	67.5	78.1	145.6	5.8	6.7	12.5
Republic of Korea	236.6	308.6	308.6	122.9	255.6	255.6	61.7	51.1	112.8	5.3	4.4	9.7
New Zealand	1.9	0.0	0.0	6.9	10.4	10.4	0.0	2.1	2.1	0.0	0.2	0.2
Other than ASEAN	**5,150.5**	**9,275.4**	**4,124.9**	**213.4**	**2,144.5**	**1,931.1**	**825.0**	**386.2**	**1,211.2**	**70.9**	**33.2**	**104.2**
Total	**5,470.1**	**10,745.3**	**5,275.2**	**581.3**	**3,002.6**	**2,421.4**	**1,046.5**	**484.3**	**1,530.7**	**90.0**	**41.6**	**131.6**

ASEAN = Association of Southeast Asian Nations, ERIA = Economic Research Institute for ASEAN and East Asia, Lao PDR = Lao People's Democratic Republic, Mtoe = million tonnes of oil equivalent.

Note: OECD Countries; 2040 generation is regarded as new generation.

Source: Author.

Table A3.2.2 Required Energy Input in Replaced Electricity Generation by Hydrogen and Natural Gas Mixed Fuel

	Coal						Natural gas					
	Scenario 1 (9:1)		Scenario 2 (8:2)		Scenario 3 (7:3)		Scenario 1 (9:1)		Scenario 2 (8:2)		Scenario 3 (7:3)	
	Gas (Mtoe)	H_2 (Mtoe)	Gas (Mtoe)	H_2 (Mtoe)	Gas (Mtoe)	H_2 (Mtoe)	Gas (Mtoe)	H_2 (Mtoe)	Gas (Mtoe)	H_2 (Mtoe)	Gas (Mtoe)	H_2 (Mtoe)
Brunei Darussalam	0.1	0.0	0.1	0.0	0.1	0.0	0.3	0.0	0.2	0.1	0.2	0.1
Cambodia	0.3	0.0	0.2	0.1	0.2	0.1	0.2	0.0	0.2	0.0	0.1	0.1
Indonesia	13.5	1.5	12.0	3.0	10.5	4.5	4.0	0.4	3.5	0.9	3.1	1.3
Lao PDR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malaysia	2.0	0.2	1.8	0.4	1.6	0.7	3.0	0.3	2.7	0.7	2.3	1.0
Myanmar	0.7	0.1	0.6	0.1	0.5	0.2	0.2	0.0	0.2	0.0	0.1	0.1
Philippines	1.7	0.2	1.5	0.4	1.3	0.6	0.9	0.1	0.8	0.2	0.7	0.3
Singapore	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.1	0.8	0.2	0.7	0.3
Thailand	1.0	0.1	0.8	0.2	0.7	0.3	1.1	0.1	1.0	0.2	0.8	0.4
Viet Nam	8.0	0.9	7.1	1.8	6.2	2.7	1.6	0.2	1.4	0.4	1.2	0.5
ASEAN	**27.2**	**3.0**	**24.2**	**6.0**	**21.2**	**9.1**	**12.0**	**1.3**	**10.7**	**2.7**	**9.4**	**4.0**
Australia	3.5	0.4	3.1	0.8	2.7	1.2	2.9	0.3	2.6	0.6	2.3	1.0
China	19.2	2.1	17.0	4.3	14.9	6.4	24.4	2.7	21.7	5.4	19.0	8.1
India	62.8	7.0	55.9	14.0	48.9	20.9	4.0	0.4	3.5	0.9	3.1	1.3
Japan	8.3	0.9	7.4	1.8	6.4	2.8	9.6	1.1	8.5	2.1	7.5	3.2
Republic of Korea	7.6	0.8	6.7	1.7	5.9	2.5	6.3	0.7	5.6	1.4	4.9	2.1
New Zealand	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.2	0.1	0.2	0.1
Other than ASEAN	**101.4**	**11.3**	**90.1**	**22.5**	**78.8**	**33.8**	**47.4**	**5.3**	**42.2**	**10.5**	**36.9**	**15.8**
Total	**128.6**	**14.3**	**114.3**	**28.6**	**100.0**	**42.9**	**59.5**	**6.6**	**52.9**	**13.2**	**46.3**	**19.8**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People’s Democratic Republic, Mtoe = million tonnes of oil equivalent.
Note: Thermal efficiency – Coal=55%, Natural gas=63%, Hydrogen=63%;
Hydrogen concentration (Natural gas: Hydrogen): Scenario 1=9:1, Scenario 2=8:2, Scenario 3=7:3.
Source: Author.

Table A3.2.3 Input Energy Balance of Hydrogen, Coal, and Natural Gas (1)

	Coal-fired								
	H_2 demand			New Natural gas demand			Replaced Coal		
	S-1 (Mtoe)	S-2 (Mtoe)	S-3 (Mtoe)	S-1 (Mtoe)	S-2 (Mtoe)	S-3 (Mtoe)	S-1 (Mtoe)	S-2 (Mtoe)	S-3 (Mtoe)
Brunei Darussalam	0.0	0.0	0.0	0.1	0.1	0.1	-0.1	-0.1	-0.1
Cambodia	0.0	0.1	0.1	0.3	0.2	0.2	-0.2	-0.2	-0.2
Indonesia	1.5	3.0	4.5	13.5	12.0	10.5	-9.5	-9.5	-9.5
Lao PDR									
Malaysia	0.2	0.4	0.7	2.0	1.8	1.6	-1.4	-1.4	-1.4
Myanmar	0.1	0.1	0.2	0.7	0.6	0.5	-0.5	-0.5	-0.5
Philippines	0.2	0.4	0.6	1.7	1.5	1.3	-1.2	-1.2	-1.2
Singapore	0.0	0.0	0.0	0.0	0.0	0.0	-0.0	-0.0	-0.0
Thailand	0.1	0.2	0.3	1.0	0.8	0.7	-0.7	-0.7	-0.7
Viet Nam	0.9	1.8	2.7	8.0	7.1	6.2	-5.6	-5.6	-5.6
ASEAN	**3.0**	**6.0**	**9.1**	**27.2**	**24.2**	**21.2**	**-19.0**	**-19.0**	**-19.0**
Australia	0.4	0.8	1.2	3.5	3.1	2.7	-2.4	-2.4	-2.4
China	2.1	4.3	6.4	19.2	17.0	14.9	-13.4	-13.4	-13.4
India	7.0	14.0	20.9	62.8	55.9	48.9	-44.0	-44.0	-44.0
Japan	0.9	1.8	2.8	8.3	7.4	6.4	-5.8	-5.8	-5.8
Republic of Korea	0.8	1.7	2.5	7.6	6.7	5.9	-5.3	-5.3	-5.3
New Zealand	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other than ASEAN	**11.3**	**22.5**	**33.8**	**101.4**	**90.1**	**78.8**	**-70.9**	**-70.9**	**-70.9**
Total	**14.3**	**28.6**	**42.9**	**128.6**	**114.3**	**100.0**	**-90.0**	**-90.0**	**-90.0**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic, Mtoe = million tonnes of oil equivalent.

Source: Author.

Table 3.2.3 Input Energy Balance of Hydrogen, Coal and Natural Gas (2)

	Natural gas-fired									Net Natural gas demand (New + Replaced)		
	H2 demand			Remained Natural gas			Replaced Natural gas					
	S-1 (Mtoe)	S-2 (Mtoe)	S-3 (Mtoe)	S-1 (Mtoe)	S-2 (Mtoe)	S-3 (Mtoe)	S-1 (Mtoe)	S-2 (Mtoe)	S-3 (Mtoe)	S-1 (Mtoe)	S-2 (Mtoe)	S-3 (Mtoe)
Brunei Darussalam	0.0	0.1	0.1	0.3	0.2	0.2	-0.0	-0.0	-0.0	0.1	0.1	0.0
Cambodia	0.0	0.0	0.1	0.2	0.2	0.1	-0.0	-0.0	-0.0	0.2	0.2	0.2
Indonesia	0.4	0.9	1.3	4.0	3.5	3.1	-0.4	-0.4	-0.4	13.1	11.6	10.1
Lao PDR												
Malaysia	0.3	0.7	1.0	3.0	2.7	2.3	-0.3	-0.3	-0.3	1.7	1.5	1.2
Myanmar	0.0	0.0	0.1	0.2	0.2	0.1	-0.0	-0.0	-0.0	0.6	0.6	0.5
Philippines	0.1	0.2	0.3	0.9	0.8	0.7	-0.1	-0.1	-0.1	1.6	1.4	1.2
Singapore	0.1	0.2	0.3	0.9	0.8	0.7	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Thailand	0.1	0.2	0.4	1.1	1.0	0.8	-0.1	-0.1	-0.1	0.8	0.7	0.6
Viet Nam	0.2	0.4	0.5	1.6	1.4	1.2	-0.2	-0.2	-0.2	7.8	6.9	6.0
ASEAN	**1.3**	**2.7**	**4.0**	**12.0**	**10.7**	**9.4**	**-1.3**	**-1.3**	**-1.3**	**25.9**	**22.8**	**19.8**
Australia	0.3	0.6	1.0	2.9	2.6	2.3	-0.3	-0.3	-0.3	3.2	2.8	2.4
China	2.7	5.4	8.1	24.4	21.7	19.0	-2.7	-2.7	-2.7	16.5	14.3	12.2
India	0.4	0.9	1.3	4.0	3.5	3.1	-0.4	-0.4	-0.4	62.4	55.4	48.4
Japan	1.1	2.1	3.2	9.6	8.5	7.5	-1.1	-1.1	-1.1	7.2	6.3	5.4
Republic of Korea	0.7	1.4	2.1	6.3	5.6	4.9	-0.7	-0.7	-0.7	6.9	6.0	5.2
New Zealand	0.0	0.1	0.1	0.3	0.2	0.2	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0
Other than ASEAN	**5.3**	**10.5**	**15.8**	**47.4**	**42.2**	**36.9**	**-5.3**	**-5.3**	**-5.3**	**96.1**	**84.8**	**73.6**
Total	**6.6**	**13.2**	**19.8**	**59.5**	**52.9**	**46.3**	**-6.6**	**-6.6**	**-6.6**	**122.0**	**107.7**	**93.4**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic, Mtoe = million tonnes of oil equivalent.

Source: Author.

Appendix 3.3 Calculation of Hydrogen Demand Potential for Industry

Table A3.3.1 Replaced Natural Gas by Hydrogen Mixed Fuel

Country	2040 Nat gas Consumption (Mtoe)	20% of Nat gas Consumption (Mtoe)	Scenario 1 (9:1) Nat gas Consumption (Mtoe)	Scenario 1 (9:1) H_2 Consumption (Mtoe)	Scenario 2 (8:2) Nat gas Consumption (Mtoe)	Scenario 2 (8:2) H_2 Consumption (Mtoe)	Scenario 3 (7:3) Nat gas Consumption (Mtoe)	Scenario 3 (7:3) H_2 Consumption (Mtoe)
Brunei Darussalam								
Cambodia								
Indonesia	12.7	2.5	2.3	0.3	2.0	0.5	1.8	0.8
Lao PDR								
Malaysia	13.1	2.6	2.4	0.3	2.1	0.5	1.8	0.8
Myanmar	1.7	0.3	0.3	0.0	0.3	0.1	0.2	0.1
Philippines	0.8	0.2	0.1	0.0	0.1	0.0	0.1	0.0
Singapore	1.9	0.4	0.3	0.0	0.3	0.1	0.3	0.1
Thailand	9.3	1.9	1.7	0.2	1.5	0.4	1.3	0.6
Viet Nam	6.5	1.3	1.2	0.1	1.0	0.3	0.9	0.4
ASEAN	**45.9**	**9.2**	**8.3**	**0.9**	**7.3**	**1.8**	**6.4**	**2.8**
Australia	8.3	1.7	1.5	0.2	1.3	0.3	1.2	0.5
China	90.1	18.0	16.2	1.8	14.4	3.6	12.6	5.4
India	33.1	6.6	6.0	0.7	5.3	1.3	4.6	2.0
Japan	15.3	3.1	2.7	0.3	2.4	0.6	2.1	0.9
Republic of Korea	11.0	2.2	2.0	0.2	1.8	0.4	1.5	0.7
New Zealand	1.1	0.2	0.2	0.0	0.2	0.0	0.2	0.1
Other than ASEAN	**158.9**	**31.8**	**28.6**	**3.2**	**25.4**	**6.4**	**22.2**	**9.5**
Total	**204.8**	**41.0**	**36.9**	**4.1**	**32.8**	**8.2**	**28.7**	**12.3**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic, Mtoe = million tonnes of oil equivalent.
Source: Author.

Appendix 3.4 Calculation of Hydrogen Demand Potential for Passenger Fuel Cell Vehicle (PFCV)

Table 3.4.1 Hydrogen Demand for PFCV

Country	Gasoline demand in 2040 (Mtoe)	Ratio of Converted to H_2			Converted to H_2 (Mtoe)		
		Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Brunei Darussalam	0.6	1.0%	5.0%	10.0%	0.01	0.03	0.06
Cambodia	1.4	1.0%	5.0%	10.0%	0.01	0.07	0.14
Indonesia	73.6	1.0%	5.0%	10.0%	0.74	3.68	7.36
Lao PDR	0.3	1.0%	5.0%	10.0%	0.00	0.01	0.03
Malaysia	29.9	1.0%	5.0%	10.0%	0.30	1.49	2.99
Myanmar	11.4	1.0%	5.0%	10.0%	0.11	0.57	1.14
Philippines	6.3	1.0%	5.0%	10.0%	0.06	0.31	0.63
Singapore	0.9	1.0%	5.0%	10.0%	0.01	0.04	0.09
Thailand	8.9	1.0%	5.0%	10.0%	0.09	0.45	0.89
Viet Nam	13.1	1.0%	5.0%	10.0%	0.13	0.66	1.31
ASEAN	**146.4**				**1.46**	**7.32**	**14.64**
Australia	13.1	2.0%	10.0%	20.0%	0.26	1.31	2.61
China	250.2	1.0%	5.0%	10.0%	2.50	12.51	25.02
India	145.8	1.0%	5.0%	10.0%	1.46	7.29	14.58
Japan	26.0	2.0%	10.0%	20.0%	0.52	2.60	5.20
Republic of Korea	8.7	2.0%	10.0%	20.0%	0.17	0.87	1.74
New Zealand	2.2	2.0%	10.0%	20.0%	0.04	0.22	0.45
Other than ASEAN	**446.0**				**4.96**	**24.80**	**49.60**
Total	**592.4**				**6.42**	**32.12**	**64.24**

hydrogen demand for PFCV

'Converted to H_2 (Mtoe)'/2.7

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic, Mtoe = million tonnes of oil equivalent, PFCV = passenger fuel cell vehicle.

Source: Author.

Appendix 3.5 Calculation of Hydrogen Demand Potential for Fuel Cell Bus (FCB)

Table 3.5.1 Hydrogen Demand for FCB

Country	Diesel demand in 2040 (Mtoe)	Ratio of Converted to H_2			Converted to H_2 (Mtoe)		
		Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Brunei Darussalam	0.3	0.025%	0.05%	0.1%	0.00	0.00	0.00
Cambodia	2.2	0.025%	0.05%	0.1%	0.00	0.00	0.00
Indonesia	84.8	0.025%	0.05%	0.1%	0.02	0.04	0.08
Lao PDR	1.2	0.025%	0.05%	0.1%	0.00	0.00	0.00
Malaysia	19.4	0.025%	0.05%	0.1%	0.00	0.01	0.02
Myanmar	0.8	0.025%	0.05%	0.1%	0.00	0.00	0.00
Philippines	12.4	0.025%	0.05%	0.1%	0.00	0.01	0.01
Singapore	1.3	0.025%	0.05%	0.1%	0.00	0.00	0.00
Thailand	18.5	0.025%	0.05%	0.1%	0.00	0.01	0.02
Viet Nam	22.8	0.025%	0.05%	0.1%	0.01	0.01	0.02
ASEAN	**163.7**				**0.04**	**0.08**	**0.16**
Australia	12.5	0.025%	0.05%	0.1%	0.00	0.01	0.01
China	180.4	0.025%	0.05%	0.1%	0.05	0.09	0.18
India	127.2	0.025%	0.05%	0.1%	0.03	0.06	0.13
Japan	15.0	0.05%	0.1%	0.2%	0.01	0.02	0.03
Republic of Korea	16.5	0.025%	0.05%	0.1%	0.00	0.01	0.02
New Zealand	1.9	0.025%	0.05%	0.1%	0.00	0.00	0.00
Other than ASEAN	**353.5**				**0.09**	**0.18**	**0.37**
Total	**517.2**				**0.13**	**0.27**	**0.53**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic, Mtoe = million tonnes of oil equivalent.

Source: Author.

Appendix 3.6 Calculation of Hydrogen Demand Potential for Fuel Cell Train (FCT)

Table 3.6.1 Hydrogen Demand Potential for Fuel Cell Train

Country	Diesel demand in 2040 (Mtoe)	Share of Rail Transport	Diesel demand for Rail Transport	Ratio of Converted to H_2			Converted to H_2 (Mtoe)		
				Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Brunei Darussalam	0.3								
Cambodia	2.2	19%	0.41	5%	10%	20%	0.02	0.04	0.08
Indonesia	84.8	10%	8.48	5%	10%	20%	0.42	0.85	1.70
Lao PDR	1.2	10%	0.12	5%	10%	20%	0.01	0.01	0.02
Malaysia	19.4	10%	1.94	5%	10%	20%	0.10	0.19	0.39
Myanmar	0.8	61%	0.51	5%	10%	20%	0.03	0.05	0.10
Philippines	12.4	10%	1.24	5%	10%	20%	0.06	0.12	0.25
Singapore	1.3								
Thailand	18.5	1%	0.12	5%	10%	20%	0.01	0.01	0.02
Viet Nam	22.8	10%	2.28	5%	10%	20%	0.11	0.23	0.46
ASEAN	**163.7**		**15.10**				**0.75**	**1.51**	**3.02**
Australia	12.5	8%	1.00	5%	10%	20%	0.05	0.10	0.20
China	180.4	3%	4.72	5%	10%	20%	0.24	0.47	0.94
India	127.2	5%	6.12	5%	10%	20%	0.31	0.61	1.22
Japan	15.0	1%	0.11	5%	10%	20%	0.01	0.01	0.02
Republic of Korea	16.5	1%	0.09	5%	10%	20%	0.00	0.01	0.02
New Zealand	1.9	2%	0.04	5%	10%	20%	0.00	0.00	0.01
Other than ASEAN	**353.5**		**12.1**				**0.60**	**1.21**	**2.42**
Total	**517.2**		**27.2**				**1.36**	**2.72**	**5.44**

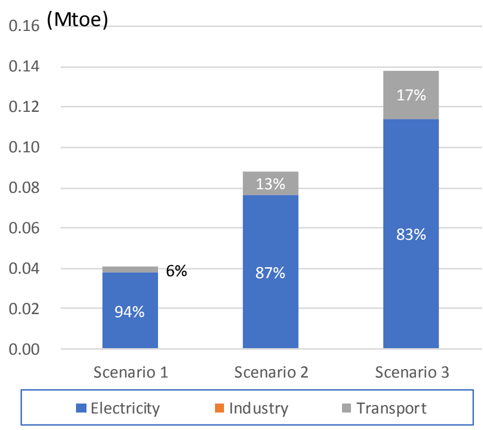
ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic, Mtoe = million tonnes of oil equivalent.
Source: Author.

Appendix 3.7 Hydrogen Demand Potential Analysis by Country

1. Brunei Darussalam

Hydrogen demand potential in Brunei Darussalam is estimated to be 0.04 Mtoe in Scenario 1, 0.09 Mtoe in Scenario 2 and 0.14 Mtoe in Scenario 3. Figure A3.7.1 shows the hydrogen demand potential by sector in Brunei Darussalam. Brunei Darussalam has no hydrogen demand potential in Industry sector.

Figure A3.7.1 Hydrogen Demand Potential by Sector (Brunei Darussalam)

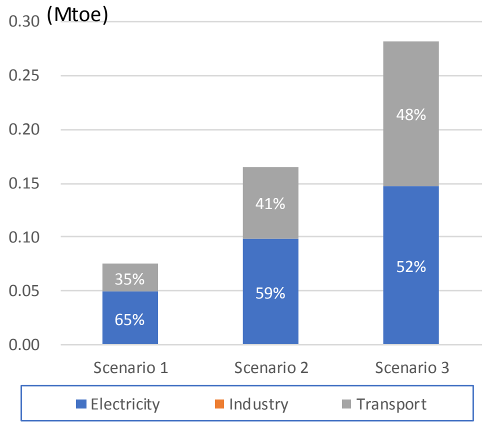


Mtoe = million tonnes of oil equivalent.
Source: Author.

2. Cambodia

Hydrogen demand potential in Cambodia is estimated to be 0.07 Mtoe in Scenario 1, 0.17 Mtoe in Scenario 2 and 0.28 Mtoe in Scenario 3. Figure A3.7.2 shows the hydrogen demand potential by sector in Cambodia. Cambodia has no potential in Industry sector.

Figure A3.7.2 Hydrogen Demand Potential by Sector (Cambodia)

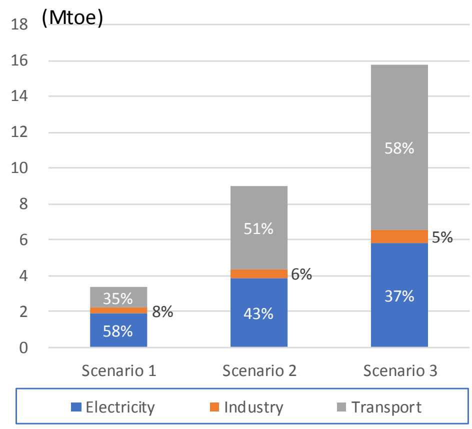


Mtoe = million tonnes of oil equivalent.
Source: Author.

3. Indonesia

Hydrogen demand potential in Indonesia is estimated to be 2.9 Mtoe in Scenario 1, 6.6 Mtoe in Scenario 2, and 11.1 Mtoe in Scenario 3. Indonesia has the largest potential in ASEAN and the third-largest potential in the East Asia Summit (EAS) region. Figure A3.7.3 shows the hydrogen demand potential by sector of Indonesia.

Figure A3.7.3 Hydrogen Demand Potential by Sector (Indonesia)

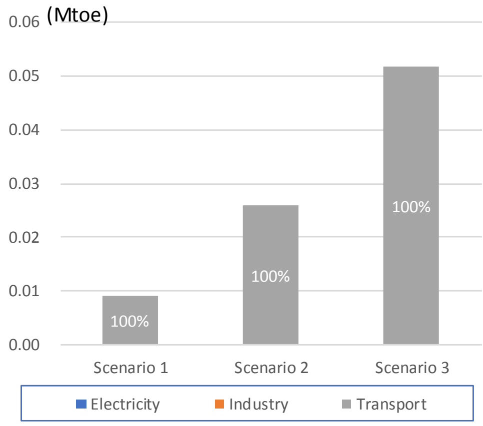


Mtoe = million tonnes of oil equivalent.
Source: Author.

4. Lao PDR

Hydrogen demand potential in Lao PDR is estimated to be 0.01 Mtoe in Scenario 1, 0.03 Mtoe in Scenario 2, and 0.05 Mtoe in Scenario 3. The following figure shows the hydrogen demand potential by sector in Lao PDR. Lao PDR has no demand potential in electricity generation sector and industry because, with no plan to introduce natural gas in the energy mix, there is no replacement target.

Figure A3.7.4 Hydrogen Demand Potential by Sector (Lao PDR)



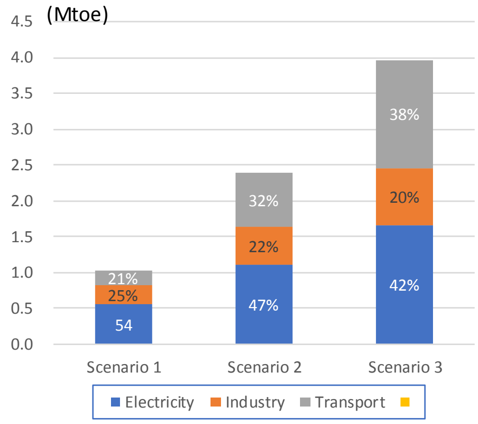
Mtoe = million tonnes of oil equivalent.

Source: Author.

5. Malaysia

Hydrogen demand potential in Malaysia is estimated to be 1.0 Mtoe in Scenario 1, 2.4 Mtoe in Scenario 2, and 4.0 Mtoe in Scenario 3. In ASEAN, Malaysia has the third-largest potential in all Scenarios. Figure A3.7.5 shows the hydrogen demand potential by sector in Malaysia.

Figure A3.7.5 Hydrogen Demand Potential by Sector (Malaysia)



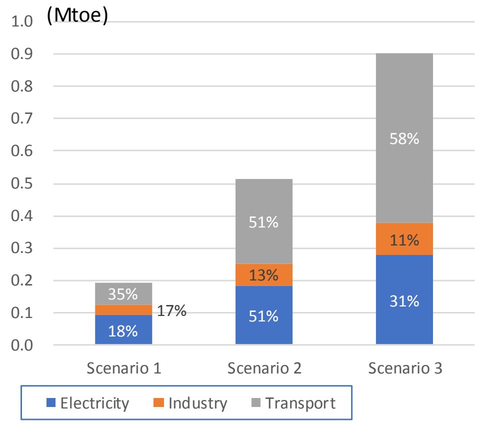
Mtoe = million tonnes of oil equivalent.

Source: Author.

6. Myanmar

Hydrogen demand potential in Myanmar is estimated to be 0.2 Mtoe in Scenario 1, 0.5 Mtoe in Scenario 2, and 0.9 Mtoe in Scenario 3. Figure A3.7.6 shows the hydrogen demand potential by sector in Myanmar. A feature of Myanmar's potential is that the transport sector share is higher than in other ASEAN countries.

Figure A3.7.6 Hydrogen Demand Potential by Sector (Myanmar)

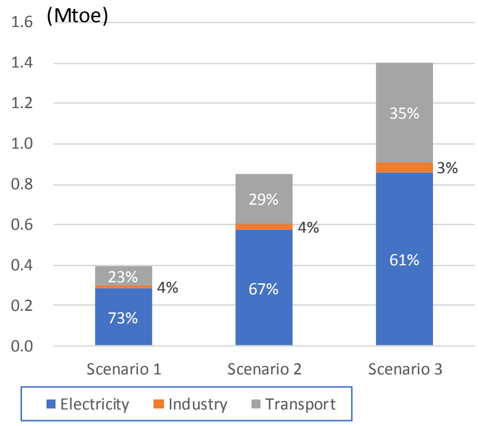


Mtoe = million tonnes of oil equivalent.
Source: Author.

7. Philippines

Hydrogen demand potential in Philippines is estimated to be 0.4 Mtoe in Scenario 1, 0.9 Mtoe in Scenario 2, and 1.4 Mtoe in Scenario 3. Figure A3.7.7 shows the hydrogen demand potential by sector in Philippines.

Figure A3.7.7 Hydrogen Demand Potential by Sector (Philippines)

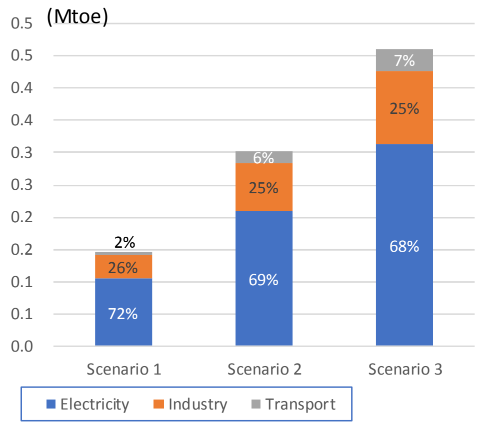


Mtoe = million tonnes of oil equivalent.
Source: Author.

8. Singapore

Hydrogen demand potential in Singapore is estimated to be 0.1 Mtoe in Scenario 1, 0.3 Mtoe in Scenario 2, and 0.5 Mtoe in Scenario 3. Figure A3.7.8 shows the hydrogen demand potential by sector in Singapore.

Figure A3.7.8 Hydrogen Demand Potential by Sector (Singapore)

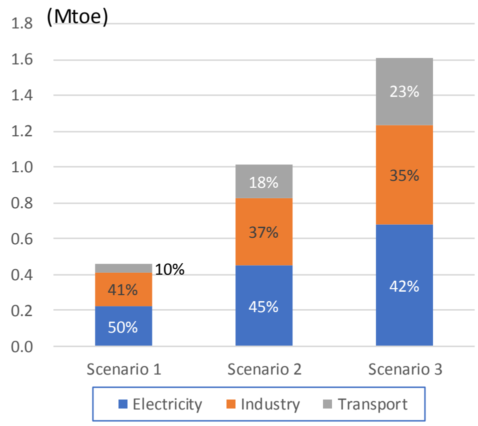


Mtoe = million tonnes of oil equivalent.
Source: Author.

9. Thailand

Hydrogen demand potential in Thailand is estimated to be 0.5 Mtoe in Scenario 1, 1.0 Mtoe in Scenario 2, and 1.6 Mtoe in Scenario 3. Figure A3.7.9 shows the hydrogen demand potential by sector in Thailand.

Figure A3.7.9 Hydrogen Demand Potential by Sector (Thailand)

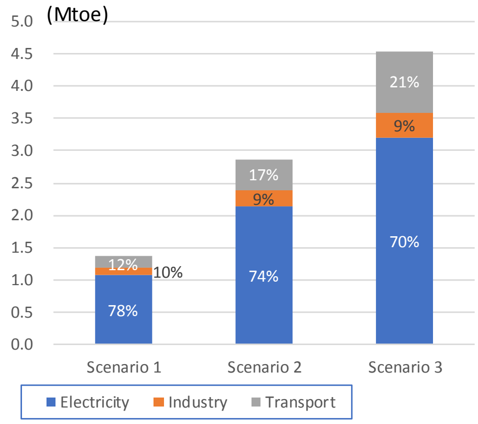


Mtoe = million tonnes of oil equivalent.
Source: Author.

10. Viet Nam

Hydrogen demand potential in Viet Nam is estimated to be 1.4 Mtoe in Scenario 1, 2.9 Mtoe in Scenario 2, and 4.6 Mtoe in Scenario 3. In ASEAN, Viet Nam has the second-largest potential in all Scenarios. Figure A3.7.10 shows the hydrogen demand potential by sector in Viet Nam.

Figure A3.7.10 Hydrogen Demand Potential by Sector (Viet Nam)

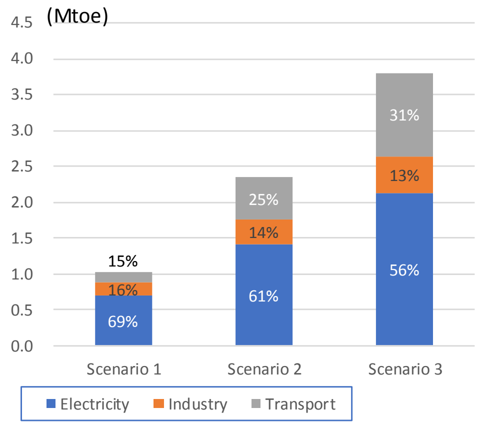


Mtoe = million tonnes of oil equivalent.
Source: Author.

11. Australia

Hydrogen demand potential in Australia is estimated to be 1.0 Mtoe in Scenario 1, 2.3 Mtoe in Scenario 2, and 3.8 Mtoe in Scenario 3. Figure A3.7.11 shows the hydrogen demand potential by sector in Australia.

Figure A3.7.11 Hydrogen Demand Potential by Sector (Australia)

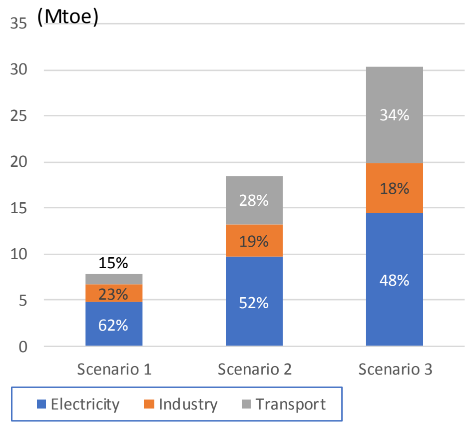


Mtoe = million tonnes of oil equivalent.
Source: Author.

12. China

Hydrogen demand potential in China is estimated to be 7.9 Mtoe in Scenario 1, 18.5 Mtoe in Scenario 2, and 30.3 Mtoe in Scenario 3. In EAS, China has the second-largest potential in all Scenarios. Figure A3.7.12 shows the hydrogen demand potential by sector in China.

Figure A3.7.12 Hydrogen Demand Potential by Sector (China)

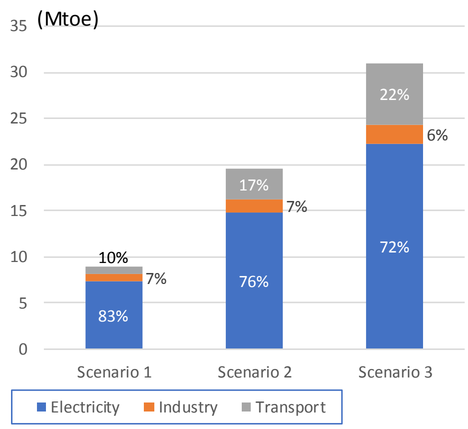


Mtoe = million tonnes of oil equivalent.
Source: Author.

13. India

Hydrogen demand potential in India is estimated to be 9.0 Mtoe in Scenario 1, 19.5 Mtoe in Scenario 2, and 31.0 Mtoe in Scenario 3. In EAS, India has the largest potential in all Scenarios. Figure A3.7.13 shows the hydrogen demand potential by sector in India.

Figure A3.7.13 Hydrogen Demand Potential by Sector (India)

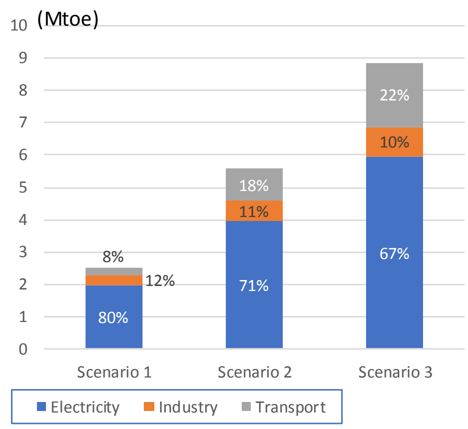


Mtoe = million tonnes of oil equivalent.
Source: Author.

14. Japan

Hydrogen demand potential in Japan is estimated to be 2.5 Mtoe in Scenario 1, 5.6 Mtoe in Scenario 2, and 8.9 Mtoe in Scenario 3. In EAS, Japan has the fourth-largest hydrogen demand potential. Figure A3.7.14 shows the hydrogen demand potential by sector in Japan.

Figure A3.7.14 Hydrogen Demand Potential by Sector (Japan)

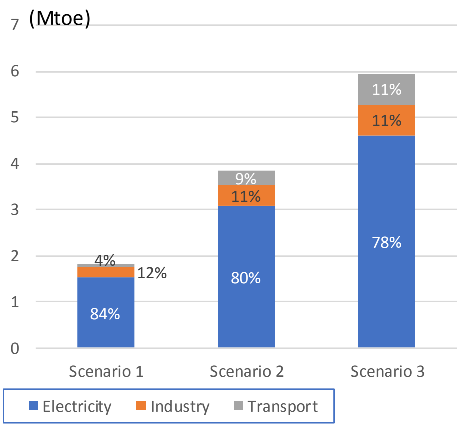


Mtoe = million tonnes of oil equivalent.
Source: Author.

15. Republic of Korea

Hydrogen demand potential in Republic of Korea (henceforth Korea) is estimated to be 1.8 Mtoe in Scenario 1, 3.9 Mtoe in Scenario 2, and 6.0 Mtoe in Scenario 3. In EAS, Korea has the fifth-largest hydrogen demand potential. Figure A3.7.15 shows the hydrogen demand potential by sector in Korea.

Figure A3.7.15 Hydrogen Demand Potential by Sector (Republic of Korea)

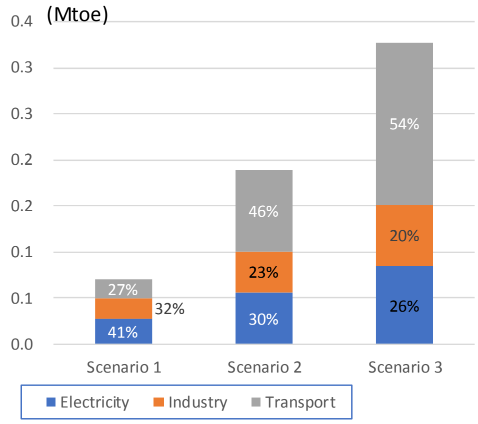


Mtoe = million tonnes of oil equivalent.
Source: Author.

16. New Zealand

Hydrogen demand potential in New Zealand is estimated to be 0.1 Mtoe in Scenario 1, 0.2 Mtoe in Scenario 2, and 0.3 Mtoe in Scenario 3. Figure A3.7.16 shows the hydrogen demand potential by sector in New Zealand. A feature of New Zealand's potential is that the share of the transport sector is higher than other many countries.

Figure A3.7.16 Hydrogen Demand Potential by Sector (New Zealand)



Mtoe = million tonnes of oil equivalent.
Source: Author.

Appendix 3.8: Impact for Coal and Natural Gas in Electricity Generation Sector

Table A3.8.1 shows the impact for coal and natural gas. Coal is replaced by hydrogen. Natural gas is not necessarily replaced by hydrogen, because replaced coal is converted to hydrogen and natural gas. Natural gas demand increases in many countries.

Table A3.8.1 Impact for Coal and Natural Gas in Electricity Generation Sector

Country	Replaced Coal (million tonnes)			Net Natural gas demand (Bcm)		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Brunei Darussalam	-0.1	-0.1	-0.1	0.1	0.1	0.0
Cambodia	-0.3	-0.3	-0.3	0.3	0.2	0.2
Indonesia	-15.4	-15.4	-15.4	13.7	12.1	10.6
Lao PDR						
Malaysia	-2.3	-2.3	-2.3	1.8	1.5	1.3
Myanmar	-0.7	-0.7	-0.7	0.7	0.6	0.5
Philippines	-1.9	-1.9	-1.9	1.7	1.5	1.3
Singapore	-0.0	-0.0	-0.0	-0.1	-0.1	-0.1
Thailand	-1.1	-1.1	-1.1	0.9	0.8	0.7
Viet Nam	-9.1	-9.1	-9.1	8.2	7.3	6.3
ASEAN	**-31.0**	**-31.0**	**-31.0**	**27.1**	**23.9**	**20.8**
Australia	-4.0	-4.0	-4.0	3.3	2.9	2.5
China	-21.9	-21.9	-21.9	17.2	15.0	12.8
India	-71.7	-71.7	-71.7	65.3	58.0	50.7
Japan	-9.5	-9.5	-9.5	7.6	6.6	5.6
Republic of Korea	-8.6	-8.6	-8.6	7.2	6.3	5.4
New Zealand	0.0	0.0	0.0	-0.0	-0.0	-0.0
Other than ASEAN	**-115.6**	**-115.6**	**-115.6**	**100.6**	**88.8**	**77.0**
Total	**-146.6**	**-146.6**	**-146.6**	**127.7**	**112.7**	**97.8**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic.
Note: Net Calorific Value of Coal = 0.6183 toe/tonne (Australian export bituminous coal, IEA)
1 toe = 1.047 * 1,000 cubic metre of Natural gas. The same applies hereafter.
Source: Author.

Appendix 3.9: CO_2 Emissions from Replaced Electricity Generation

Table A3.9.1 CO_2 Emissions from Replaced Electricity Generation

Country	Coal (million tonnes)				Natural gas (million tonnes)			
		Scenario 1	Scenario 2	Scenario 3		Scenario 1	Scenario 2	Scenario 3
	Coal 100%	Gas 90%	Gas 80%	Gas 70%	Gas 100%	Gas 90%	Gas 80%	Gas 70%
Brunei Darussalam	0.5	0.2	0.2	0.2	0.7	0.6	0.5	0.5
Cambodia	1.4	0.6	0.6	0.5	0.4	0.4	0.4	0.3
Indonesia	68.2	31.8	28.3	24.7	10.3	9.3	8.3	7.2
Lao PDR								
Malaysia	10.2	4.8	4.2	3.7	7.8	7.0	6.2	5.5
Myanmar	3.3	1.5	1.4	1.2	0.5	0.4	0.4	0.3
Philippines	8.5	3.9	3.5	3.1	2.4	2.1	1.9	1.7
Singapore	0.1	0.0	0.0	0.0	2.4	2.2	1.9	1.7
Thailand	4.8	2.2	2.0	1.7	2.8	2.5	2.3	2.0
Viet Nam	40.3	18.8	16.7	14.6	4.1	3.7	3.3	2.9
ASEAN	**137.2**	**63.9**	**56.8**	**49.7**	**31.4**	**28.3**	**25.2**	**22.0**
Australia	17.5	8.2	7.3	6.4	7.6	6.8	6.1	5.3
China	96.6	45.0	40.0	35.0	63.8	57.4	51.0	44.6
India	316.8	147.6	131.2	114.8	10.4	9.4	8.3	7.3
Japan	41.8	19.5	17.3	15.1	25.0	22.5	20.0	17.5
Republic of Korea	38.2	17.8	15.8	13.9	16.4	14.8	13.1	11.5
New Zealand	0.0	0.0	0.0	0.0	0.7	0.6	0.5	0.5
Other than ASEAN	**511.0**	**238.1**	**211.6**	**185.2**	**123.9**	**111.5**	**99.1**	**86.7**
Total	**648.2**	**302.0**	**268.5**	**234.9**	**155.3**	**139.8**	**124.2**	**108.7**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic.
Note: CO_2 factor: Bituminous coal = 3.961 tonne-CO_2/toe, Natural gas = 2.349 tonne-CO_2/toe.
Source: Author.

Table 3.9.2 CO_2 Emissions Reduction in Electricity Generation Sector

Country	Coal-fired			Natural gas-fired			Total		
	Scenario 1 (million tonnes)	Scenario 2 (million tonnes)	Scenario 3 (million tonnes)	Scenario 1 (million tonnes)	Scenario 2 (million tonnes)	Scenario 3 (million tonnes)	Scenario 1 (million tonnes)	Scenario 2 (million tonnes)	Scenario 3 (million tonnes)
Brunei Darussalam	0.2	0.3	0.3	0.1	0.1	0.2	0.3	0.4	0.5
Cambodia	0.7	0.8	0.9	0.0	0.1	0.1	0.8	0.9	1.0
Indonesia	36.4	40.0	43.5	1.0	2.1	3.1	37.5	42.0	46.6
Lao PDR									
Malaysia	5.4	6.0	6.5	0.8	1.6	2.3	6.2	7.5	8.8
Myanmar	1.8	1.9	2.1	0.0	0.1	0.1	1.8	2.0	2.2
Philippines	4.5	5.0	5.4	0.2	0.5	0.7	4.8	5.4	6.1
Singapore	0.0	0.0	0.0	0.2	0.5	0.7	0.3	0.5	0.8
Thailand	2.6	2.8	3.1	0.3	0.6	0.8	2.9	3.4	3.9
Viet Nam	21.5	23.6	25.7	0.4	0.8	1.2	21.9	24.4	26.9
ASEAN	**73.3**	**80.4**	**87.5**	**3.1**	**6.3**	**9.4**	**76.4**	**86.7**	**96.9**
Australia	9.4	10.3	11.2	0.8	1.5	2.3	10.1	11.8	13.5
China	51.6	56.6	61.6	6.4	12.8	19.1	58.0	69.4	80.7
India	169.2	185.6	202.0	1.0	2.1	3.1	170.2	187.7	205.1
Japan	22.3	24.5	26.7	2.5	5.0	7.5	24.8	29.5	34.2
Republic of Korea	20.4	22.4	24.4	1.6	3.3	4.9	22.1	25.7	29.3
New Zealand	0.0	0.0	0.0	0.1	0.1	0.2	0.1	0.1	0.2
Other than ASEAN	**272.9**	**299.4**	**325.8**	**12.4**	**24.8**	**37.2**	**285.3**	**324.1**	**363.0**
Total	**346.2**	**379.7**	**413.3**	**15.5**	**31.1**	**46.6**	**361.7**	**410.8**	**459.9**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic.

Note: CO_2 factor: Bituminous coal = 3.961 tonne-CO_2/toe, Natural gas = 2.349 tonne-CO_2/toe.

Source: Author.

Appendix 3.10. Replaced Energy by Hydrogen in Industry Sector

Table A3.10.1 Replaced Natural Gas by Hydrogen in Industry sector in 2040(in Bcm)

Country	Scenario 1	Scenario 2	Scenario 3
Brunei Darussalam			
Cambodia			
Indonesia	-0.3	-0.5	-0.8
Lao PDR			
Malaysia	-0.3	-0.5	-0.8
Myanmar	-0.0	-0.1	-0.1
Philippines	-0.0	-0.0	-0.0
Singapore	-0.0	-0.1	-0.1
Thailand	-0.2	-0.4	-0.6
Viet Nam	-0.1	-0.3	-0.4
ASEAN	**-1.0**	**-1.9**	**-2.9**
Australia	-0.2	-0.3	-0.5
China	-1.9	-3.8	-5.7
India	-0.7	-1.4	-2.1
Japan	-0.3	-0.6	-1.0
Republic of Korea	-0.2	-0.5	-0.7
New Zealand	-0.0	-0.0	-0.1
Other than ASEAN	**-3.3**	**-6.7**	**-10.0**
Total	**-4.3**	**-8.6**	**-12.9**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic.
Source: Author.

Appendix 3.11. CO_2 Emissions in Industry Sector

Table A3.11.1 CO_2 Emissions from Replaced Natural Gas in Industry

Country	Gas 100%	Scenario 1 Gas 90%	Scenario 2 Gas 80%	Scenario 3 Gas 70%
Brunei Darussalam				
Cambodia				
Indonesia	6.0	5.4	4.8	4.2
Lao PDR				
Malaysia	6.1	5.5	4.9	4.3
Myanmar	0.8	0.7	0.6	0.5
Philippines	0.4	0.3	0.3	0.3
Singapore	0.9	0.8	0.7	0.6
Thailand	4.4	3.9	3.5	3.1
Viet Nam	3.1	2.8	2.5	2.1
ASEAN	**21.6**	**19.4**	**17.3**	**15.1**
Australia	3.9	3.5	3.1	2.7
China	42.3	38.1	33.8	29.6
India	15.6	14.0	12.4	10.9
Japan	7.2	6.5	5.7	5.0
Republic of Korea	5.2	4.6	4.1	3.6
New Zealand	0.5	0.5	0.4	0.4
Other than ASEAN	**74.7**	**67.2**	**59.7**	**52.3**
Total	**96.2**	**86.6**	**77.0**	**67.4**

Table A3.11.2 CO_2 Emissions Reduction

Country	Scenario 1 (million tonnes)	Scenario 2 (million tonnes)	Scenario 3 (million tonnes)
Brunei Darussalam			
Cambodia			
Indonesia	0.6	1.2	1.8
Lao PDR			
Malaysia	0.6	1.2	1.8
Myanmar	0.1	0.2	0.2
Philippines	0.0	0.1	0.1
Singapore	0.1	0.2	0.3
Thailand	0.4	0.9	1.3
Viet Nam	0.3	0.6	0.9
ASEAN	**2.2**	**4.3**	**6.5**
Australia	0.4	0.8	1.2
China	4.2	8.5	12.7
India	1.6	3.1	4.7
Japan	0.7	1.4	2.2
Republic of Korea	0.5	1.0	1.5
New Zealand	0.1	0.1	0.2
Other than ASEAN	**7.5**	**14.9**	**22.4**
Total	**9.6**	**19.2**	**28.9**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic.
Note: CO_2 factor: Natural gas = 2.349 tonne-CO_2/toe.
Source: Author.

Appendix 3.12. Replaced Energy by Hydrogen in Transport Sector

1. Gasoline

Table A3.12.1 Replaced Gasoline Demand by Hydrogen in Transport Sector in 2040(in thousand tonnes)

Country	Scenario 1 PFCV	Scenario 2 PFCV	Scenario 3 PFCV
Brunei Darussalam	-6	-30	-59
Cambodia	-13	-66	-132
Indonesia	-691	-3,455	-6,909
Lao PDR	-2	-12	-24
Malaysia	-281	-1,403	-2,806
Myanmar	-107	-536	-1,072
Philippines	-59	-295	-590
Singapore	-8	-42	-84
Thailand	-84	-418	-837
Viet Nam	-123	-615	-1,230
ASEAN	**-1,374**	**-6,871**	**-13,743**
Australia	-245	-1,225	-2,450
China	-2,349	-11,745	-23,490
India	-1,369	-6,844	-13,689
Japan	-489	-2,443	-4,885
Republic of Korea	-163	-814	-1,629
New Zealand	-42	-210	-419
Other than ASEAN	**-4,656**	**-23,281**	**-46,562**
Total	**-6,031**	**-30,153**	**-60,305**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic, PFCV = passenger fuel cell vehicle.

Note: Net Calorific Value of Gasoline = 1.0653 toe/tonne (Japan, IEA). The same applies hereafter.

Source: Author.

2. Diesel

Table A3.12.2 Replaced Diesel Demand by Hydrogen in FCB and FCT sector in 2040

(in thousand tonnes)

Country	Scenario 1			Scenario 2			Scenario 3		
	FCB	FCT	Total	FCB	FCT	Total	FCB	FCT	Total
Brunei Darussalam	-0		-0	-0		-0	-0		-0
Cambodia	-1	-20	-20	-1	-40	-41	-2	-80	-82
Indonesia	-21	-417	-437	-42	-833	-875	-83	-1,667	-1,750
Lao PDR	-0	-6	-6	-1	-12	-13	-1	-24	-26
Malaysia	-5	-95	-100	-10	-190	-200	-19	-380	-399
Myanmar	-0	-25	-25	-0	-50	-50	-1	-100	-100
Philippines	-3	-61	-64	-6	-122	-128	-12	-245	-257
Singapore	-0		-0	-1		-1	-1		-1
Thailand	-5	-6	-11	-9	-12	-21	-18	-24	-42
Viet Nam	-6	-112	-118	-11	-224	-235	-22	-448	-470
ASEAN	**-40**	**-742**	**-782**	**-80**	**-1,484**	**-1,564**	**-161**	**-2,967**	**-3,128**
Australia	-3	-49	-52	-6	-98	-105	-12	-197	-209
China	-44	-232	-276	-89	-464	-553	-177	-928	-1,106
India	-31	-301	-332	-63	-601	-664	-125	-1,202	-1,327
Japan	-7	-5	-13	-15	-11	-26	-30	-22	-51
Republic of Korea	-4	-4	-9	-8	-9	-17	-16	-18	-34
New Zealand	-0	-2	-3	-1	-4	-5	-2	-8	-10
Other than ASEAN	**-91**	**-594**	**-684**	**-181**	**-1,188**	**-1,369**	**-362**	**-2,375**	**-2,737**
Total	**-131**	**-1,336**	**-1,466**	**-262**	**-2,671**	**-2,933**	**-523**	**-5,343**	**-5,866**

ASEAN = Association of Southeast Asian Nations, FCB = fuel cell bus, FCT = fuel cell train, Lao PDR = Lao People's Democratic Republic.
Note: Net Calorific Value of Diesel = 1.0175 toe/tonne (Japan, IEA).
Source: Author.

Appendix 3.13 Hydrogen Demand and Replaced Diesel by Hydrogen

Table A3.13.1 Replaced Diesel by Hydrogen

Country	H_2 demand (Mtoe)			Replaced Diesel (thousand tonnes)		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Brunei Darussalam						
Cambodia	0.02	0.04	0.08	-20	-40	-80
Indonesia	0.42	0.85	1.70	-417	-833	-1,667
Lao PDR	0.01	0.01	0.02	-6	-12	-24
Malaysia	0.10	0.19	0.39	-95	-190	-380
Myanmar	0.03	0.05	0.10	-25	-50	-100
Philippines	0.06	0.12	0.25	-61	-122	-245
Singapore				0	0	0
Thailand	0.01	0.01	0.02	-6	-12	-24
Viet Nam	0.11	0.23	0.46	-112	-224	-448
ASEAN	0.75	1.51	3.02	-742	-1,484	-2,967
Australia	0.05	0.10	0.20	-49	-98	-197
China	0.24	0.47	0.94	-232	-464	-928
India	0.31	0.61	1.22	-301	-601	-1,202
Japan	0.01	0.01	0.02	-5	-11	-22
Republic of Korea	0.00	0.01	0.02	-4	-9	-18
New Zealand	0.00	0.00	0.01	-2	-4	-8
Other than ASEAN	0.60	1.21	2.42	-594	-1,188	-2,375
Total	1.36	2.72	5.44	-1,336	-2,671	-5,343

Table A3.13.2 CO_2 Emissions from Replaced Diesel

Country	Scenario 1 (million tonnes)	Scenario 2 (million tonnes)	Scenario 3 (million tonnes)
Brunei Darussalam			
Cambodia	0.1	0.1	0.3
Indonesia	1.3	2.6	5.3
Lao PDR	0.0	0.0	0.1
Malaysia	0.3	0.6	1.2
Myanmar	0.1	0.2	0.3
Philippines	0.2	0.4	0.8
Singapore			
Thailand	0.0	0.0	0.1
Viet Nam	0.4	0.7	1.4
ASEAN	2.3	4.7	9.4
Australia	0.2	0.3	0.6
China	0.7	1.5	2.9
India	0.9	1.9	3.8
Japan	0.0	0.0	0.1
Republic of Korea	0.0	0.0	0.1
New Zealand	0.0	0.0	0.0
Other than ASEAN	1.9	3.7	7.5
Total	4.2	8.4	16.9

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People’s Democratic Republic, Mtoe = million tonnes of oil equivalent.

Source: Author.

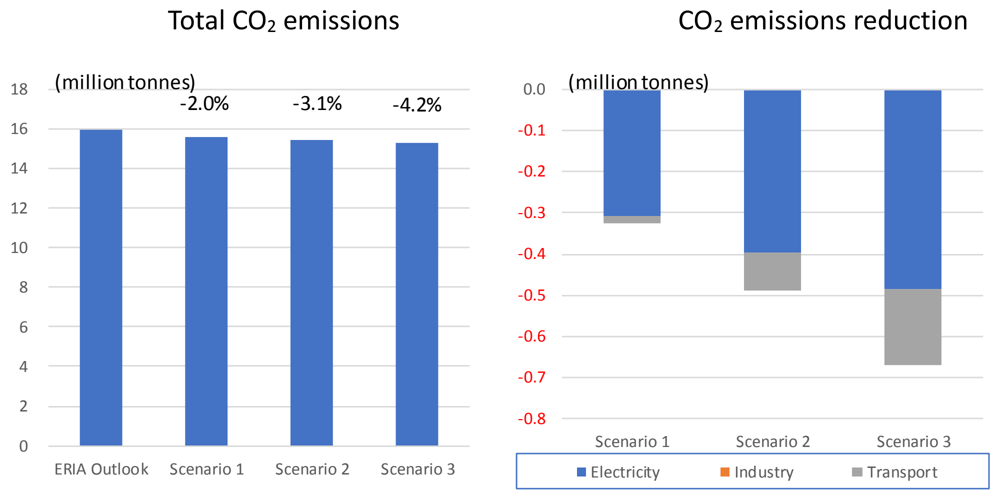
Appendix 3.14 CO_2 Emissions Reduction Analysis by Country

1. Brunei Darussalam

Total CO_2 emissions reduction in Brunei Darussalam reaches 0.3 million tonnes in Scenario 1, 0.5 million tonnes in Scenario 2, and 0.7 million tonnes in Scenario 3.

Figure A3.14.1 shows the total CO_2 emissions from fuel combustion and emissions reduction by sector in Brunei Darussalam. There is no CO_2 emissions reduction from the transport sector in Brunei Darussalam.

Figure A3.14.1 CO_2 Emissions Reduction (Brunei Darussalam)



ERIA = Economic Research Institute for ASEAN and East Asia.

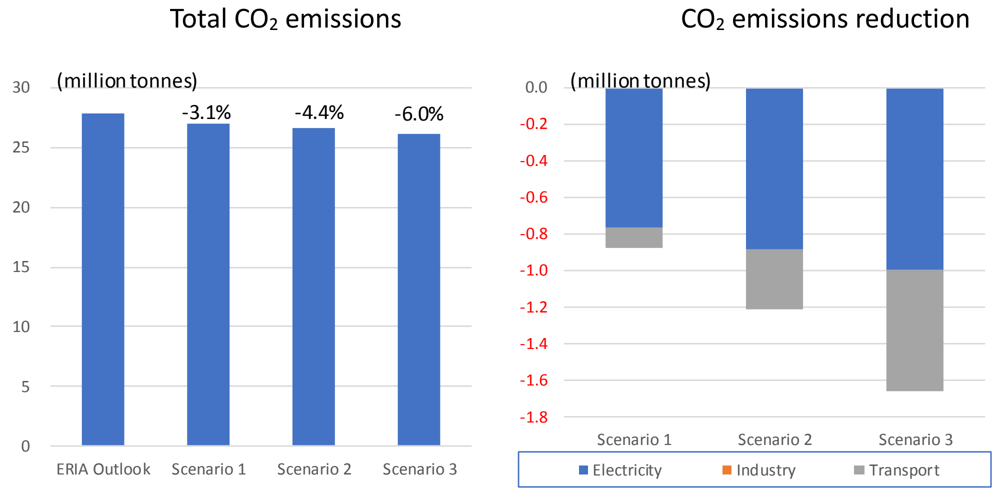
Source: Author.

2. Cambodia

CO_2 emissions reduction in Cambodia reaches 0.9 million tonnes in Scenario 1, 1.2 million tonnes in Scenario 2, and 1.7 million tonnes in Scenario 3.

Figure A3.14.2 shows the total CO_2 emissions from fuel combustion and CO_2 emissions reduction by sector in Cambodia. There is no CO_2 emissions reduction from the industry sector in Cambodia.

Figure A3.14.2 CO_2 Emissions Reduction (Cambodia)



ERIA = Economic Research Institute for ASEAN and East Asia.

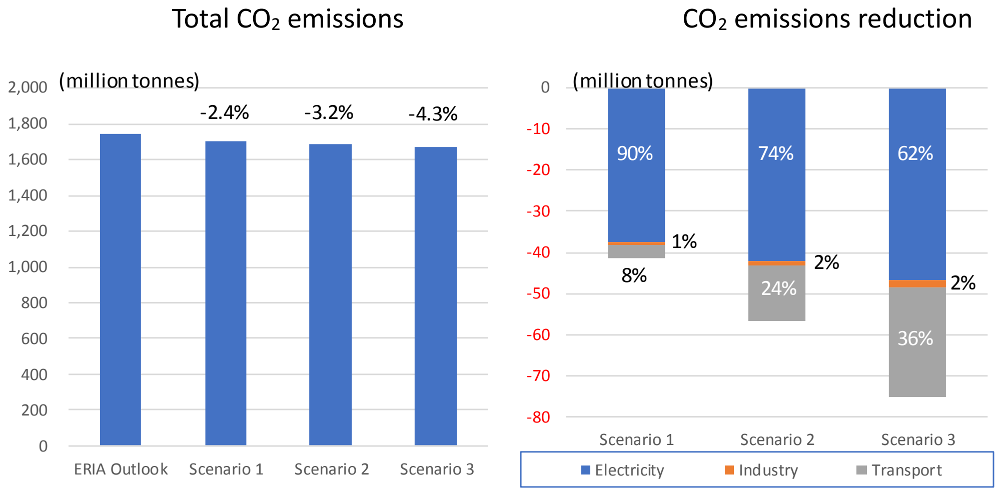
Source: Author.

3. Indonesia

CO_2 emissions reduction in Indonesia reaches 41.6 million tonnes in Scenario 1, 56.7 million tonnes in Scenario 2, and 75.3 million tonnes in Scenario 3. Indonesia has a large CO_2 emissions reduction potential with a higher share of coal-fired electricity generation because 20% of coal-fired new electricity generation is assumed to be converted to hydrogen and natural gas mixed fuel, which emits less CO_2 than coal. Indonesia has the largest CO_2 reduction potential in ASEAN and the third-largest CO_2 reduction potential in EAS.

Figure A3.14.3 shows the total CO_2 emissions from fuel combustion and CO_2 emissions reduction by sector in Indonesia.

Figure A3.14.3 CO_2 Emissions Reduction (Indonesia)



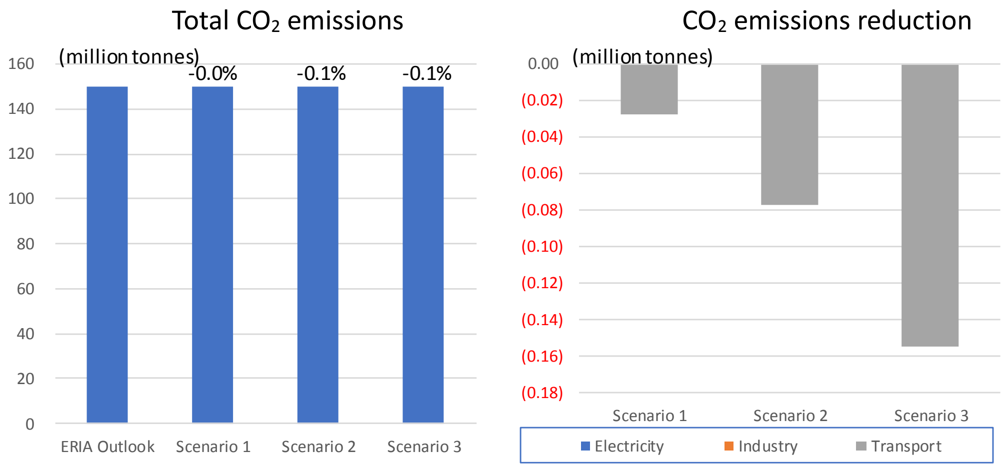
ERIA = Economic Research Institute for ASEAN and East Asia.
Source: Author.

4. Lao PDR

CO_2 emissions reduction in Lao PDR reaches 41.6 million tonnes in Scenario 1, 56.7 million tonnes in Scenario 2, and 75.3 million tonnes in Scenario 3.

Figure A3.14.4 shows the total CO_2 emissions from fuel combustion and CO_2 emissions reduction by sector in Lao PDR. There is no CO_2 emissions reduction from the electricity generation and industry sectors in Lao PDR.

Figure A3.14.4 CO_2 Emissions Reduction (Lao PDR)



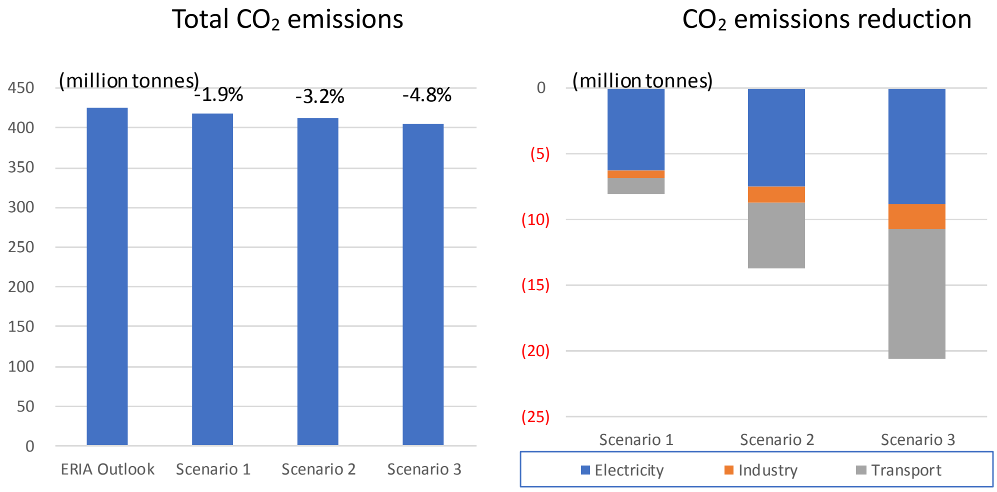
ERIA = Economic Research Institute for ASEAN and East Asia.
Source: Author.

5. Malaysia

CO_2 emissions reduction in Malaysia reaches 8.0 million tonnes in Scenario 1, 13.7 million tonnes in Scenario 2 and 20.6 million tonnes in Scenario 3.

Figure A3.14.5 shows the total CO_2 emissions from fuel combustion and CO_2 emissions reduction by sector in Malaysia.

Figure A3.14.5 CO_2 Emissions Reduction (Malaysia)



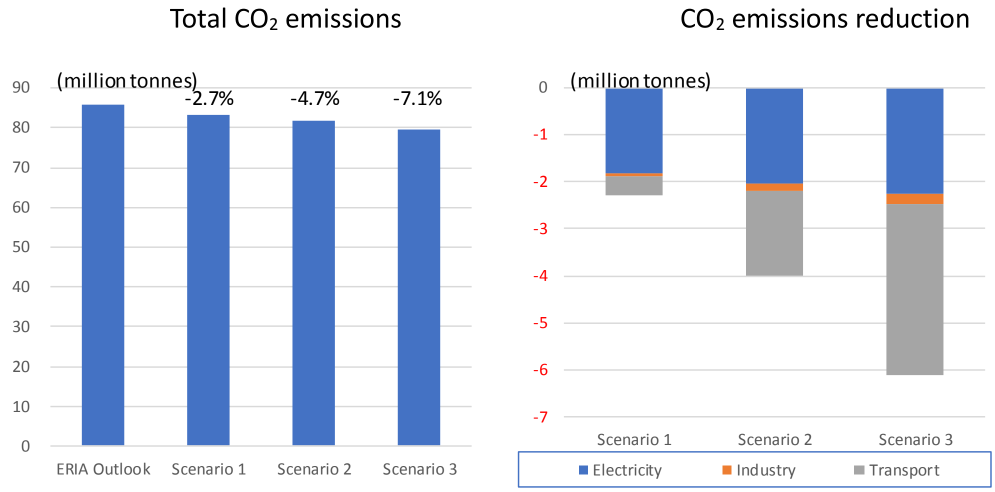
ERIA = Economic Research Institute for ASEAN and East Asia.
Source: Author.

6. Myanmar

CO_2 emissions reduction in Myanmar reaches 2.3 million tonnes in Scenario 1, 4.0 million tonnes in Scenario 2, and 6.1 million tonnes in Scenario 3.

Figure A3.14.6 shows the total CO_2 emissions from fuel combustion and CO_2 emissions reduction by sector in Myanmar.

Figure A3.14.6 CO_2 Emissions Reduction (Myanmar)



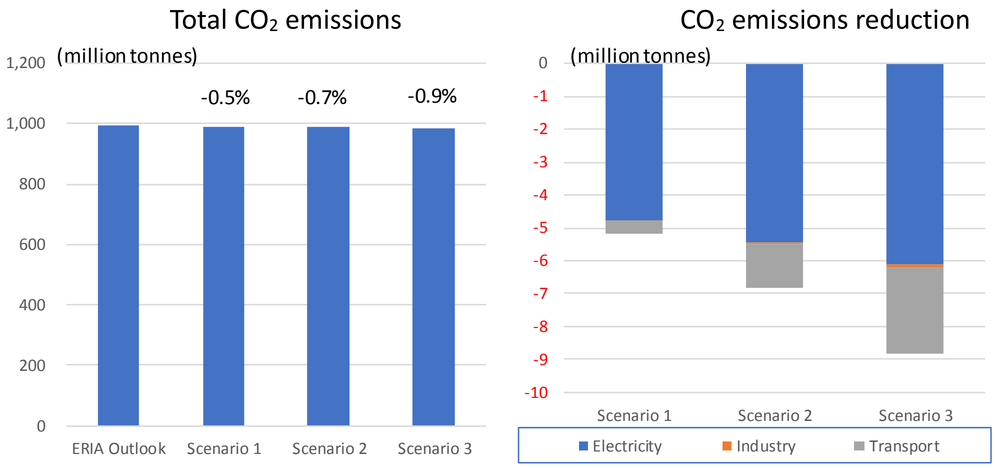
ERIA = Economic Research Institute for ASEAN and East Asia.
Source: Author.

7. Philippines

CO_2 emissions reduction in the Philippines reaches 5.2 million tonnes in Scenario 1, 6.8 million tonnes in Scenario 2, and 8.8 million tonnes in Scenario 3.

Figure A3.14.7 shows the total CO_2 emissions from fuel combustion and CO_2 emissions reduction by sector in the Philippines.

Figure A3.14.7 CO_2 Emissions Reduction (Philippines)



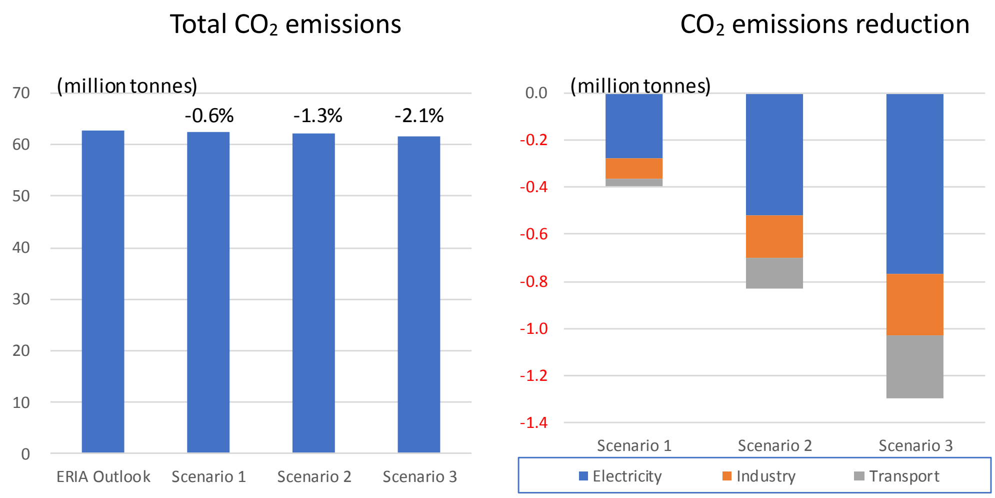
ERIA = Economic Research Institute for ASEAN and East Asia.
Source: Author.

8. Singapore

CO_2 emissions reduction in Singapore reaches 0.4 million tonnes in Scenario 1, 0.8 million tonnes in Scenario 2, and 1.3 million tonnes in Scenario 3.

Figure A3.14.8 shows the total CO_2 emissions from fuel combustion and CO_2 emissions reduction by sector in Singapore.

Figure A3.14.8 CO_2 Emissions Reduction (Singapore)



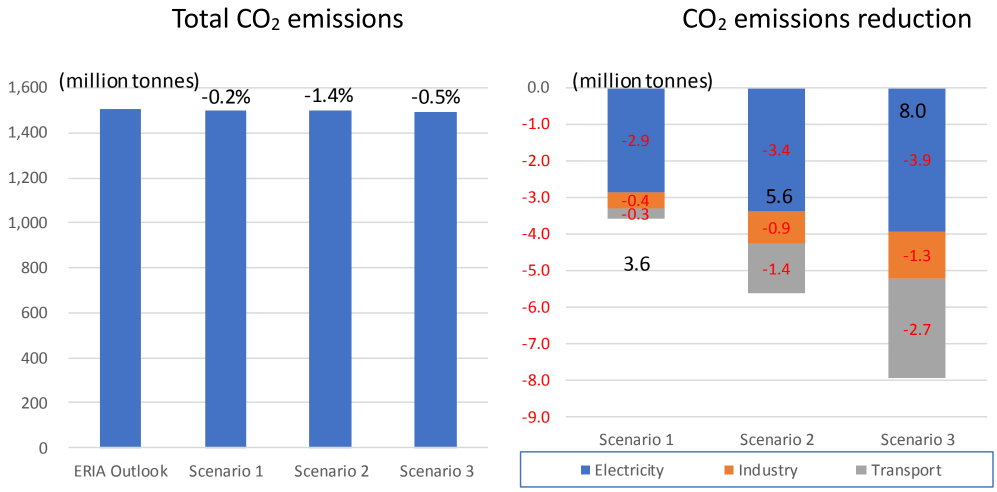
ERIA = Economic Research Institute for ASEAN and East Asia.
Source: Author.

9. Thailand

CO_2 emissions reduction in Thailand reaches 0.4 million tonnes in Scenario 1, 0.8 million tonnes in Scenario 2, and 1.3 million tonnes in Scenario 3.

Figure A3.14.9 shows the total CO_2 emissions from fuel combustion and CO_2 emissions reduction by sector in Thailand.

Figure A3.14.9 CO_2 Emissions Reduction (Thailand)



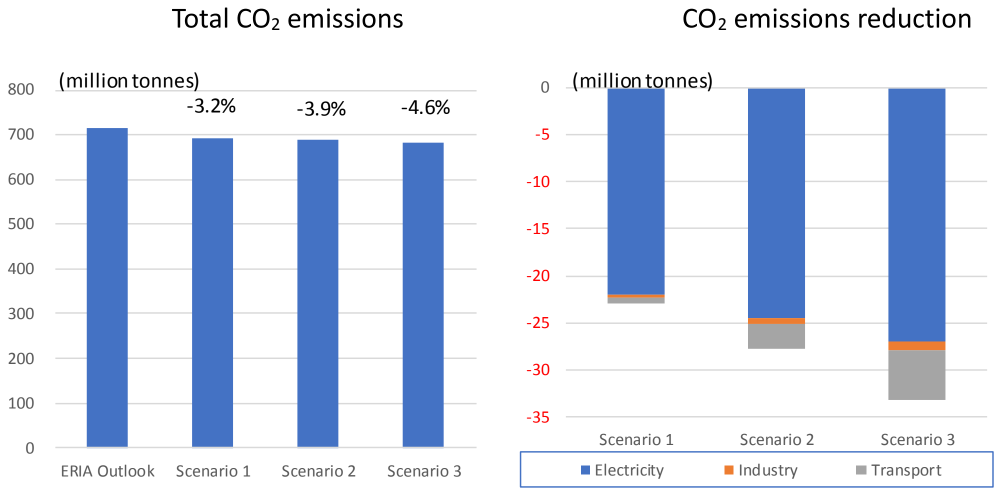
ERIA = Economic Research Institute for ASEAN and East Asia.
Source: Author.

10. Viet Nam

CO_2 emissions reduction in Viet Nam reaches 23.0 million tonnes in Scenario 1, 27.7 million tonnes in Scenario 2, and 33.2 million tonnes in Scenario 3. Viet Nam has a large CO_2 emissions reduction potential with a higher share of coal-fired electricity generation because 20% of coal-fired new electricity generation is assumed to be converted to hydrogen and natural gas mixed fuel. Viet Nam has the second-largest CO_2 reduction potential in ASEAN.

Figure A3.14.10 shows the total CO_2 emissions from fuel combustion and CO_2 emissions reduction by sector in Viet Nam.

Figure A3.14.10 CO_2 Emissions Reduction (Viet Nam)



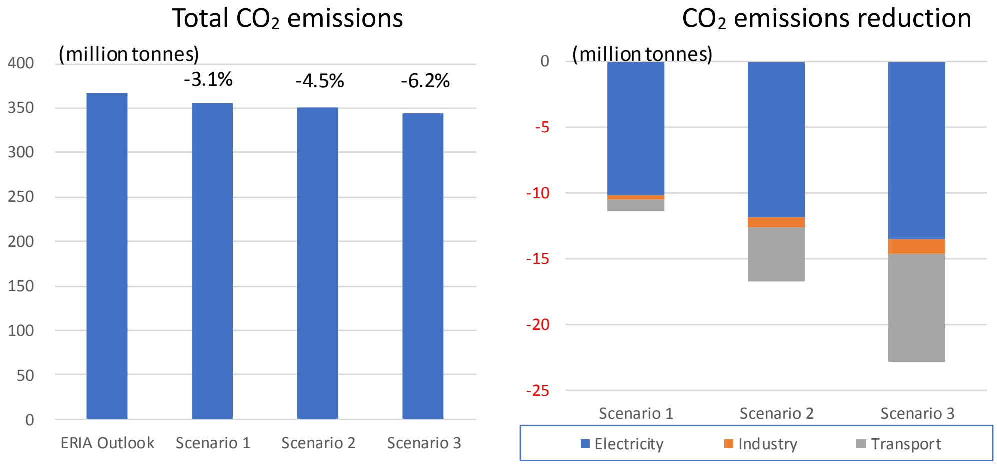
ERIA = Economic Research Institute for ASEAN and East Asia.
Source: Author.

11. Australia

CO_2 emissions reduction in Australia reaches 11.4 million tonnes in Scenario 1, 16.7 million tonnes in Scenario 2, and 22.9 million tonnes in Scenario 3.

Figure A3.14.11 shows the total CO_2 emissions from fuel combustion and CO_2 emissions reduction by sector in Australia.

Figure A3.14.11 CO_2 Emissions Reduction (Australia)



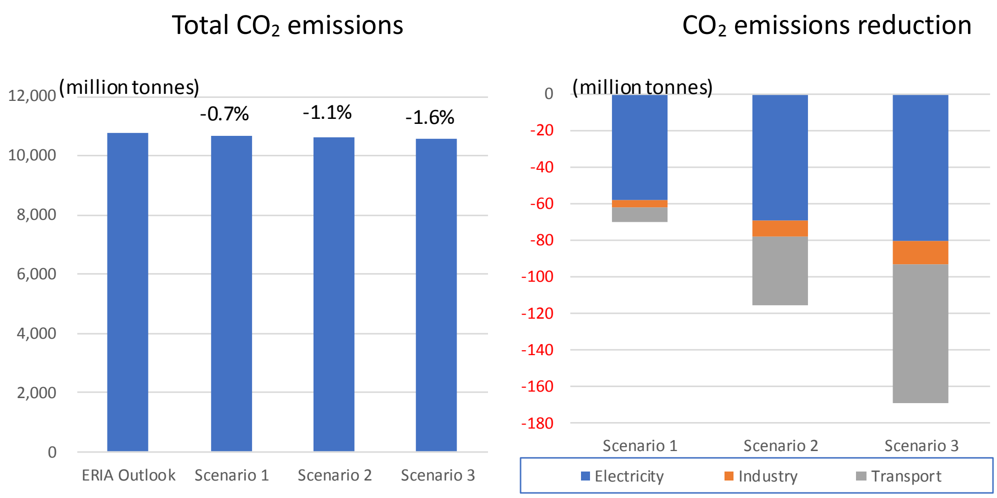
ERIA = Economic Research Institute for ASEAN and East Asia.
Source: Author.

12. China

CO_2 emissions reduction in China reaches 70.3 million tonnes in Scenario 1, 115.9 million tonnes in Scenario 2, and 169.5 million tonnes in Scenario 3. China has the second-largest CO_2 reduction potential in EAS.

Figure A3.14.12 shows the total CO_2 emissions from fuel combustion and CO_2 emissions reduction by sector in China.

Figure A3.14.12 CO_2 Emissions Reduction (China)



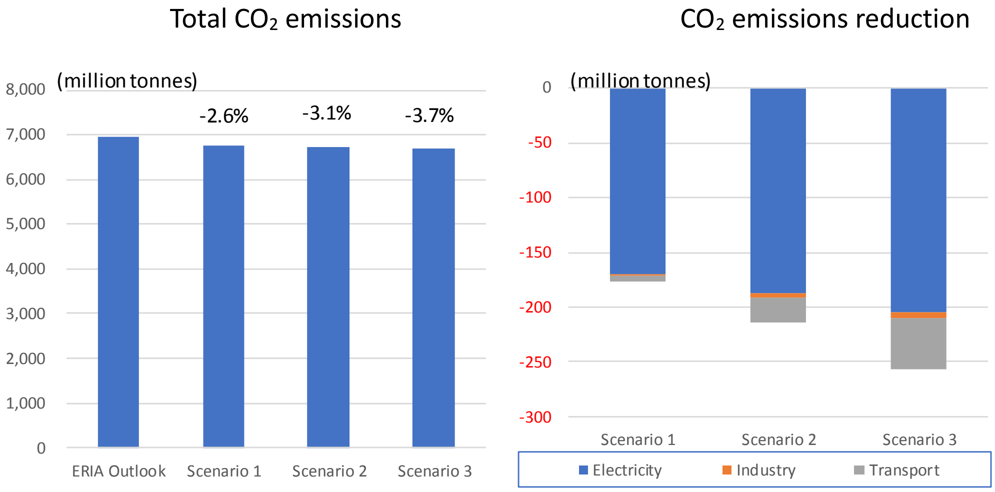
ERIA = Economic Research Institute for ASEAN and East Asia.
Source: Author.

13. India

CO_2 emissions reduction in India reaches 177.1 million tonnes in Scenario 1, 214.0 million tonnes in Scenario 2, and 256.3 million tonnes in Scenario 3. India has the largest CO_2 reduction potential with 37% share in the EAS region. The share of coal-fire electricity generation is one of the highest in the region.

Figure A3.14.13 shows the total CO_2 emissions from fuel combustion and CO_2 emissions reduction by sector in India.

Figure A3.14.13 CO_2 Emissions Reduction (India)



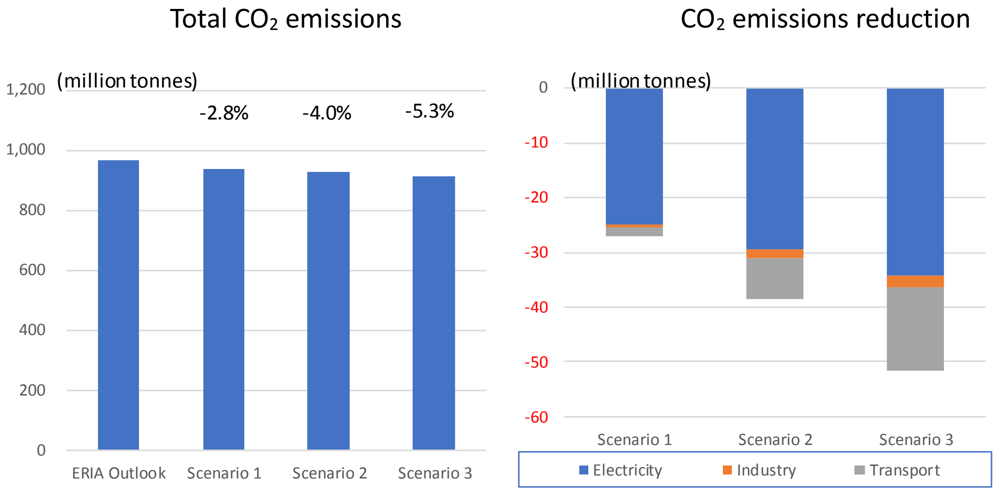
ERIA = Economic Research Institute for ASEAN and East Asia.
Source: Author.

14. Japan

CO_2 emissions reduction in Japan reaches 27.1 million tonnes in Scenario 1, 38.6 million tonnes in Scenario 2, and 51.6 million tonnes in Scenario 3.

Figure A3.14.14 shows the total CO_2 emissions from fuel combustion and CO_2 emissions reduction by sector in Japan.

Figure A3.14.14 CO_2 Emissions Reduction (Japan)



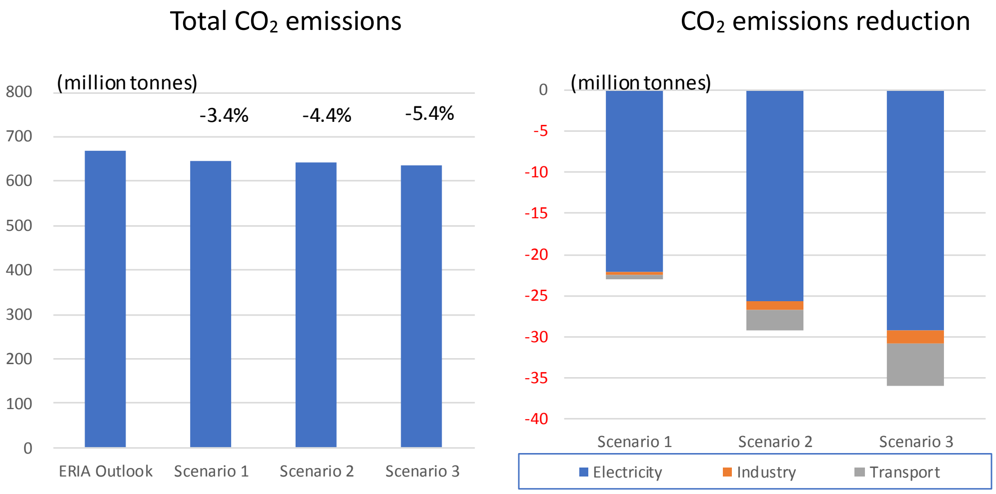
ERIA = Economic Research Institute for ASEAN and East Asia.
Source: Author.

15. Korea

CO_2 emissions reduction in Korea reaches 23.1 million tonnes in Scenario 1, 29.3 million tonnes in Scenario 2, and 36.0 million tonnes in Scenario 3.

Figure A3.14.15 shows the total CO_2 emissions from fuel combustion and CO_2 emissions reduction by sector in Korea.

Figure A3.14.15 CO_2 Emissions Reduction (Republic of Korea)



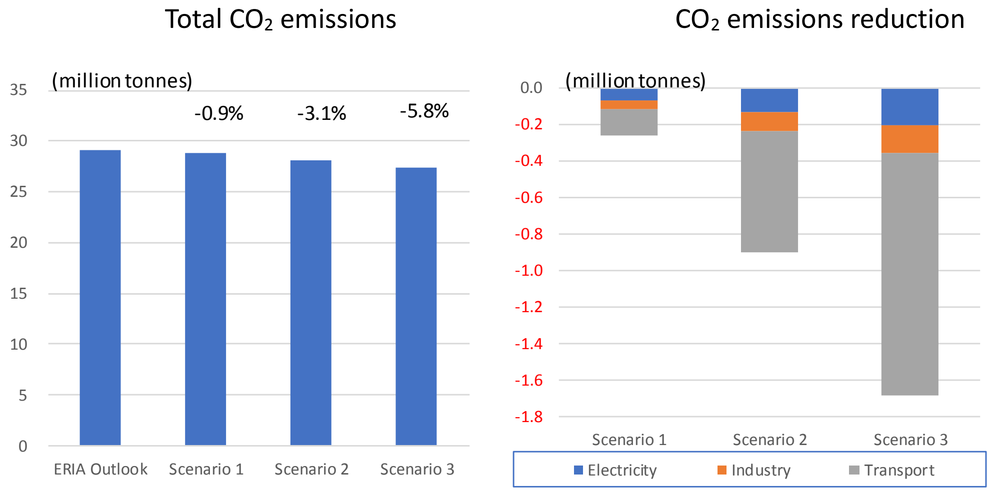
ERIA = Economic Research Institute for ASEAN and East Asia.
Source: Author.

16. New Zealand

CO_2 emissions reduction in New Zealand reaches 0.3 million tonnes in Scenario 1, 0.9 million tonnes in Scenario 2, and 1.7 million tonnes in Scenario 3.

Figure A3.14.15 shows the total CO_2 emissions from fuel combustion and CO_2 emissions reduction by sector in New Zealand.

Figure A3.14.15 CO_2 Emissions Reduction (New Zealand)



ERIA = Economic Research Institute for ASEAN and East Asia.
Source: Author.

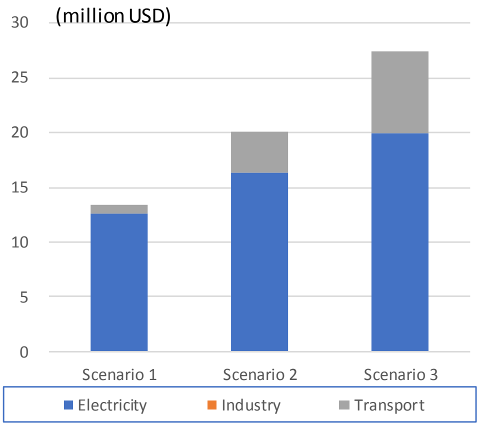
Appendix 3.15 Economic Impact of CO_2 Emissions Reduction Analysis by Country

1. Brunei Darussalam

The economic impact of CO_2 emissions reduction in Brunei Darussalam reaches $13 million in Scenario 1, $20 million in Scenario 2, and $27 million in Scenario 3.

Figure A3.15.1 shows the economic impact of CO_2 emissions reduction by sector in Brunei Darussalam.

Figure A3.15.1 Economic Impact of CO_2 Emissions Reduction (Brunei Darussalam)



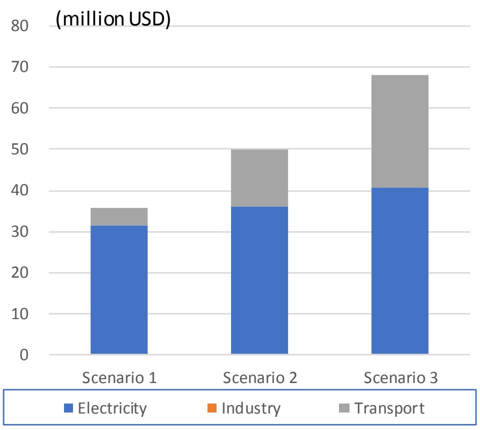
Source: Author.

2. Cambodia

The economic impact of CO_2 emissions reduction in Cambodia reaches $36 million in Scenario 1, $50 million in Scenario 2, and $68 million in Scenario 3.

Figure A3.15.2 shows the economic impact of CO_2 emissions reduction by sector in Cambodia.

Figure A3.15.2 Economic Impact of CO_2 Emissions Reduction (Cambodia)



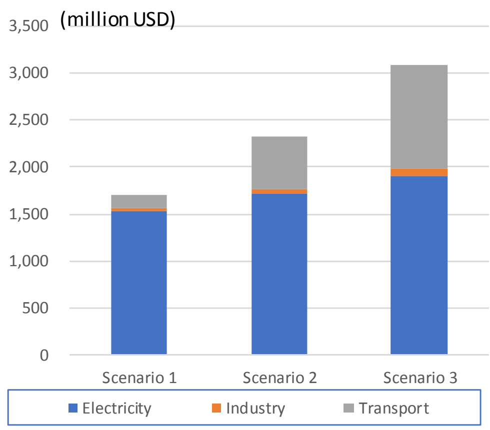
Source: Author.

3. Indonesia

The economic impact of CO_2 emissions reduction in Indonesia reaches $1.7 billion in Scenario 1, $2.3 billion in Scenario 2, and $3.1 billion in Scenario 3. Indonesia has the largest economic impact of CO_2 emissions reduction in ASEAN and the third-largest economic impact of CO_2 emissions reduction in the EAS region.

Figure A3.15.3 shows the economic impact of CO_2 emissions reduction by sector in Indonesia.

Figure A3.15.3 Economic Impact of CO_2 Emissions Reduction (Indonesia)



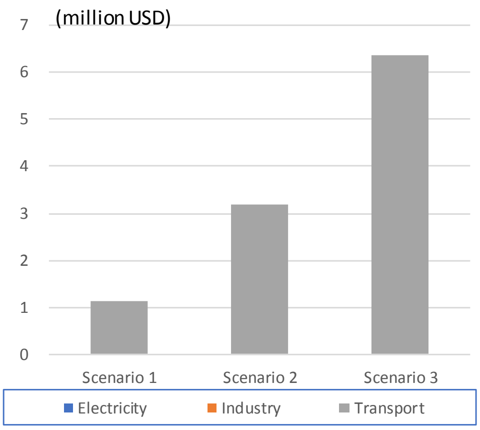
Source: Author.

4. Lao PDR

The economic impact of CO_2 emissions reduction in Lao PDR reaches $1 million in Scenario 1, $3 million in Scenario 2, and $6 million in Scenario 3.

Figure A3.15.4 shows the economic impact of CO_2 emissions reduction by sector in Lao PDR.

Figure A3.15.4 Economic Impact of CO_2 Emissions Reduction (Lao PDR)



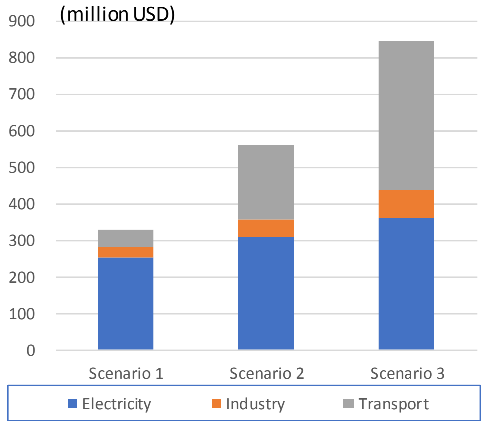
Lao PDR = Lao People's Democratic Republic.
Source: Author.

5. Malaysia

The economic impact of CO_2 emissions reduction in Malaysia reaches $329 million in Scenario 1, $563 million in Scenario 2, and $845 million in Scenario 3.

Figure A3.15.5 shows the economic impact of CO_2 emissions reduction by sector in Malaysia.

Figure A3.15.5 Economic Impact of CO_2 Emissions Reduction (Malaysia)



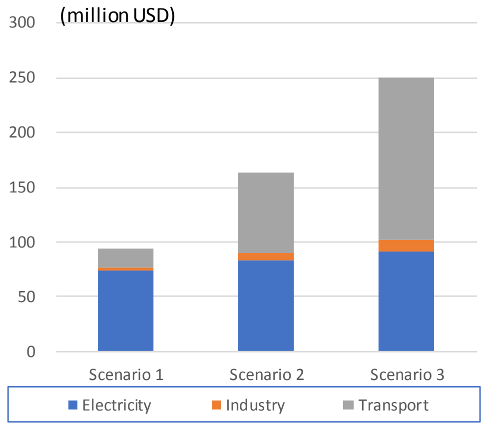
Source: Author.

6. Myanmar

The economic impact of CO_2 emissions reduction in Myanmar reaches $94 million in Scenario 1, $164 million in Scenario 2, and $250 million in Scenario 3.

Figure A3.15.6 shows the economic impact of CO_2 emissions reduction by sector in Myanmar.

Figure A3.15.6 Economic Impact of CO_2 Emissions Reduction (Myanmar)



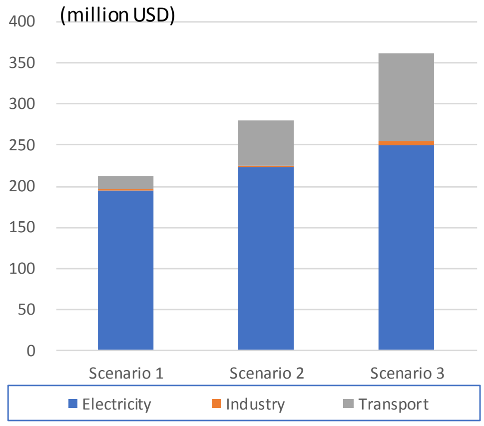
Source: Author.

7. Philippines

The economic impact of CO_2 emissions reduction in the Philippines reaches $94 million in Scenario 1, $164 million in Scenario 2, and $250 million in Scenario 3.

Figure A3.15.7 shows the economic impact of CO_2 emissions reduction by sector in the Philippines.

Figure A3.15.7 Economic Impact of CO_2 Emissions Reduction (Philippines)



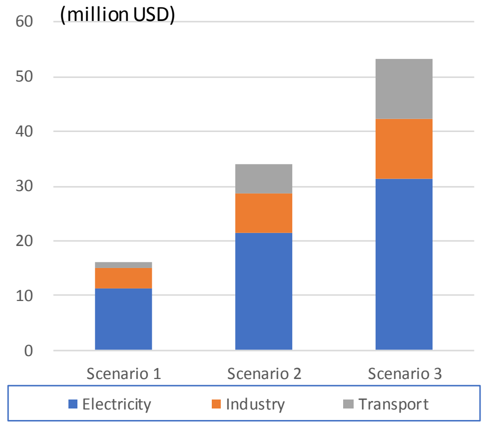
Source: Author.

8. Singapore

The economic impact of CO_2 emissions reduction in Singapore reaches $16 million in Scenario 1, $34 million in Scenario 2, and $53 million in Scenario 3.

Figure A3.15.8 shows the economic impact of CO_2 emissions reduction by sector in Singapore.

Figure A3.15.8 Economic Impact of CO_2 Emissions Reduction (Singapore)



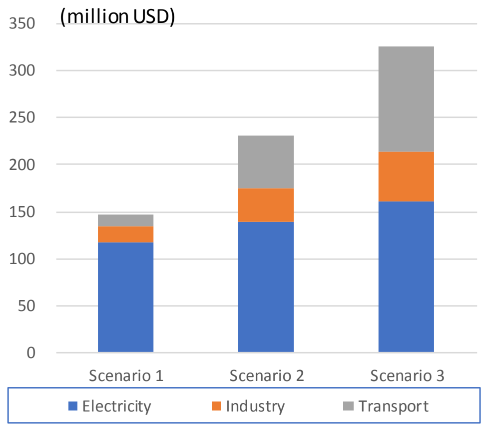
Source: Author.

9. Thailand

The economic impact of CO_2 emissions reduction in Thailand reaches $147 million in Scenario 1, $231 million in Scenario 2, and $326 million in Scenario 3.

Figure A3.15.9 shows the economic impact of CO_2 emissions reduction by sector in Thailand.

Figure A3.15.9 Economic Impact of CO_2 Emissions Reduction (Thailand)



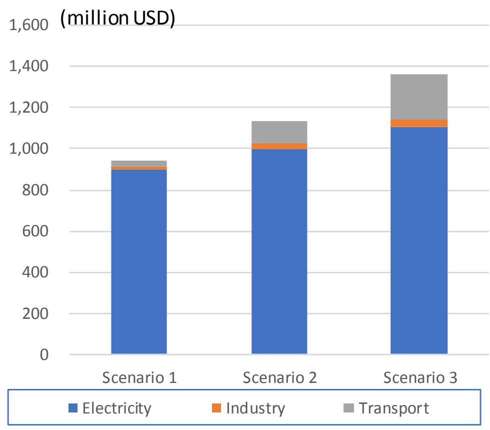
Source: Author.

10. Viet Nam

The economic impact of CO_2 emissions reduction in Viet Nam reaches \$0.9 billion in Scenario 1, \$1.1 billion in Scenario 2, and \$1.4 billion in Scenario 3.

Figure A.15.10 shows the economic impact of CO_2 emissions reduction by sector in Viet Nam.

Figure A.15.10 Economic Impact of CO_2 Emissions Reduction (Viet Nam)



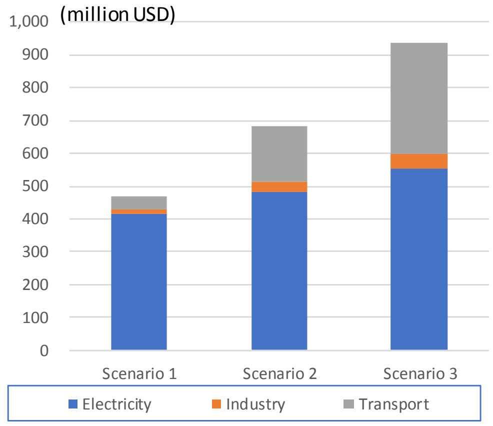
Source: Author.

11. Australia

The economic impact of CO_2 emissions reduction in Australia reaches \$469 million in Scenario 1, \$684 million in Scenario 2, and \$938 million in Scenario 3.

Figure A3.15.11 shows the economic impact of CO_2 emissions reduction by sector in Australia.

Figure A3.15.11 Economic Impact of CO_2 Emissions Reduction (Australia)



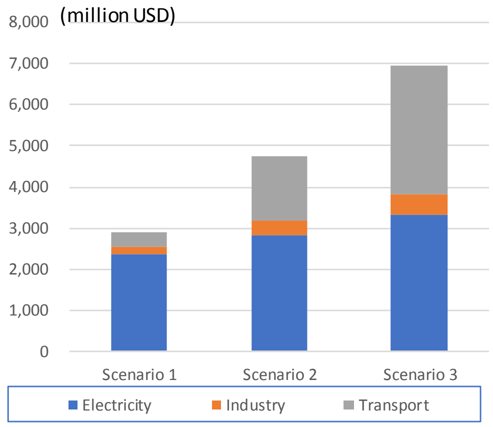
Source: Author.

12. China

The economic impact of CO_2 emissions reduction in China reaches $2.9 billion in Scenario 1, $4.8 billion in Scenario 2, and $7.0 billion in Scenario 3. China has the second-largest economic impact of CO_2 emissions reduction in EAS.

Figure A3.15.12 shows the economic impact of CO_2 emissions reduction by sector in China.

Figure A3.15.12 Economic Impact of CO_2 Emissions Reduction (China)



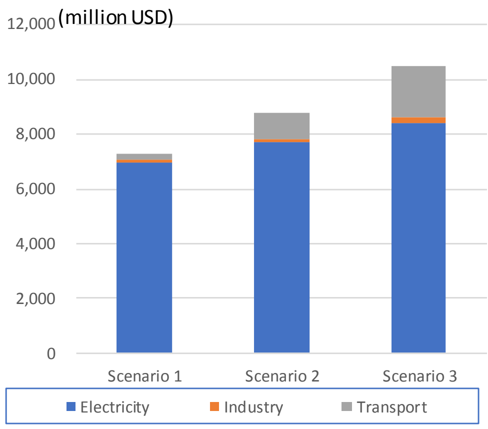
Source: Author.

13. India

The economic impact of CO_2 emissions reduction in India reaches \$7.3 billion in Scenario 1, \$8.8 billion in Scenario 2, and \$10.5 billion in Scenario 3. India has the largest economic impact of CO_2 emissions reduction in EAS.

Figure A3.15.13 shows the economic impact of CO_2 emissions reduction by sector in India.

Figure A3.15.13 Economic Impact of CO_2 Emissions Reduction (India)



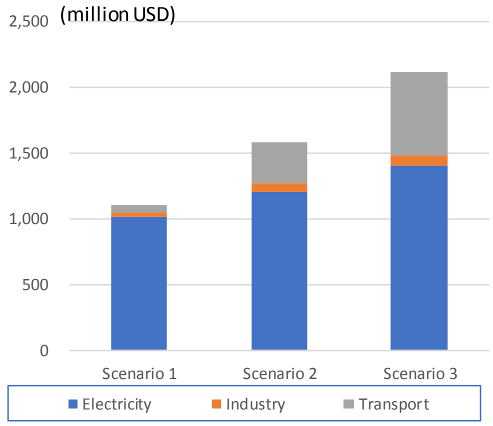
Source: Author.

14. Japan

The economic impact of CO_2 emissions reduction in Japan reaches \$1.1 billion in Scenario 1, \$1.6 billion in Scenario 2, and \$2.1 billion in Scenario 3.

Figure A3.15.14 shows the economic impact of CO_2 emissions reduction by sector in Japan.

Figure A3.15.14 Economic Impact of CO_2 Emissions Reduction (Japan)



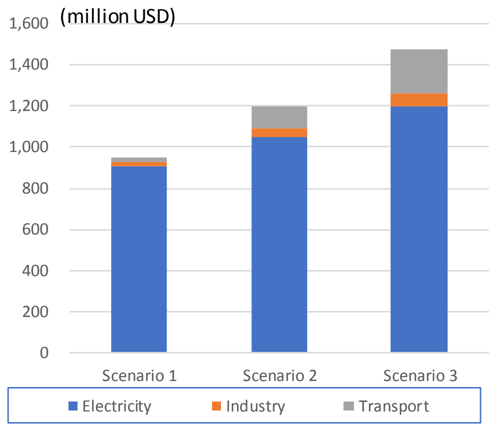
Source: Author.

15. Republic of Korea

The economic impact of CO_2 emissions reduction in Korea reaches $0.9 billion in Scenario 1, $1.2 billion in Scenario 2, and $1.5 billion in Scenario 3.

Figure A3.15 15 shows the economic impact of CO_2 emissions reduction by sector in Korea.

Figure A3.15 15 Economic Impact of CO_2 Emissions Reduction (Republic of Korea)



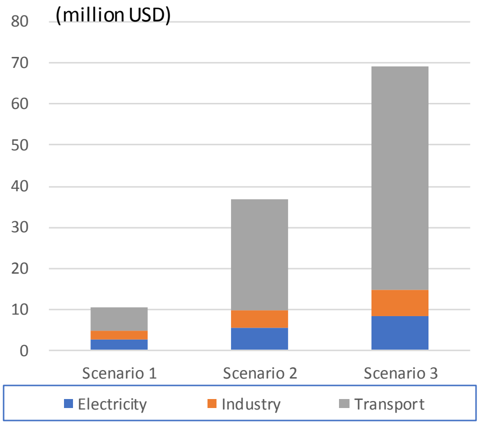
Source: Author.

16. New Zealand

The economic impact of CO_2 emissions reduction in New Zealand reaches $11 million in Scenario 1, $37 million in Scenario 2, and $69 million in Scenario 3.

Figure A3.15.16 shows the economic impact of CO_2 emissions reduction by sector in New Zealand.

Figure A3.15.16 Economic Impact of CO_2 Emissions Reduction (New Zealand)



Source: Author.