Chapter 2

Hydrogen Demand Potential (Phase 2)

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Chapter 2

Hydrogen Demand Potential (Phase 2)

Future hydrogen demand potential is difficult to estimate due to many uncertainties, including promotion policies. In the phase 1 study in FY2018, based on ERIA's energy outlook, the working group (WG) created assumptions and scenarios to estimate the hydrogen demand potential. In this phase 2, we conducted a hearing on hydrogen power generation amongst experts from Mitsubishi Hitachi Power Systems and on fuel cell vehicles (FCVs) from Toyota Motor Corporation to revise the scenarios.

First, we reviewed the assumptions and scenarios for the calculation of the hydrogen demand potential in phase 1. Next, we re-estimated the hydrogen demand potential based on the revised assumptions and scenarios and compared it with that of the phase 1 study.

1. Review of Hydrogen Demand Potential in Phase 1

This section reviews the hydrogen demand potential in phase 1.

1.1. Basic assumptions (Phase 1)

Table 2.1 shows the basic assumptions of the phase 1 study, which were also applied to phase 2.

Table 2.1: Basic Assumptions for Estimating Hydrogen Demand Potential (Phase 1)

The national hydrogen pipeline, as well as refuelling stations, will only be partially established in 2040.
Hydrogen demand for chemicals and hydrogen carriers, e.g. ammonia or methanol, is excluded.[a]
Hydrogen utilisation technologies to be fully commercialised in 2040: ● Utility scale gas turbine fuelled by a mixture of hydrogen and natural gas ● Commercial scale boiler fuelled by a mixture of hydrogen and natural gas ● Passenger fuel cell vehicle ● Fuel cell bus ● Fuel cell train
Technologies that need to be developed 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.
Hydrogen demand for stationary fuel cell is not included in this study because we assumed that hydrogen for stationary fuel cell would be produced from on-site natural gas reforming, which can be categorised as natural gas demand.

[a] 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 (IEEJ, 2015).
Source: ERIA (2018).

1.2. Other assumptions and conversion factors (Phase 1)

Table 2.2 shows the assumptions and conversion factors used in the phase 1 study, which were applied to phase 2.

Table 2.2: Other Assumptions and Conversion Factors (Phase 1)

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: IEA (2018)
Net calorific value	Other bituminous coal (Australian export coal) 0.6138 toe/tonne	Source: IEA, World Energy Balances 2018 database
H2 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: METI–ANRE (2017)
Conversion factor	1 GJ = 0.02388 toe 1 cal = 4.187 J 1 Gcal = 0.1 toe 1 MWh = 0.086 toe 1 MMBtu = 0.0252 toe	–

ANRE = Agency for Natural Resources and Energy; IEA = International Energy Agency; METI = Ministry of Economy, Trade, and Industry, Japan.
Source: ERIA (2018).

1.3. Summary of scenarios (Phase 1)

Table 2.3 summarises the scenarios to calculate hydrogen demand potential in the phase 1 study.

Table 2.3: Summary of Scenarios (Phase 1)

<table>
<tr><th>Sector</th><th>Fuel</th><th></th><th>Scenario 1</th><th>Scenario 2</th><th>Scenario 3</th></tr>
<tr><td rowspan="2">Electricity generation</td><td>Coal</td><td>20% of new coal-fired electricity generation will be converted to natural gas and H2 mixed fuel–fired generation</td><td colspan="3">H2 concentration of mixed fuel</td></tr>
<tr><td>Natural gas</td><td>20% of new natural gas–fired electricity generation will be converted to natural gas and H2 mixed fuel–fired generation</td><td rowspan="2">H2: 10%
Natural gas: 90%</td><td rowspan="2">H2: 20%
Natural gas: 80%</td><td rowspan="2">H2: 30%
Natural gas: 70%</td></tr>
<tr><td>Industry</td><td>Natural gas</td><td>20% of natural gas consumption for industrial purposes will be replaced by natural gas and H2 mixed fuel</td></tr>
<tr><td rowspan="6">Transport</td><td rowspan="2">Gasoline</td><td rowspan="2">Passenger fuel cell vehicle:
Gasoline demand will be converted to H2</td><td colspan="3">Share of H2/gasoline for passenger cars</td></tr>
<tr><td>OECD
H2: 2.0%
Gasoline: 98%
Non-OECD
H2: 1.0%
Gasoline: 99%</td><td>OECD
H2: 10%
Gasoline: 90%
Non-OECD
H2: 5%
Gasoline: 95%</td><td>OECD
H2: 20%
Gasoline: 80%
Non-OECD
H2: 10%
Gasoline: 90%</td></tr>
<tr><td rowspan="2">Diesel</td><td rowspan="2">Fuel cell bus:
Diesel demand will be converted to H2</td><td colspan="3">Share of H_2/diesel for buses</td></tr>
<tr><td>Japan
H_2: 0.05%
Gasoline: 99.95%
Other countries
H2: 0.025%
Gasoline: 99.975%</td><td>Japan
H_2: 0.1%
Gasoline: 99.9%
Other countries
H2: 0.05%
Gasoline: 99.95%</td><td>Japan
H_2: 0.2%
Gasoline: 99.8%
Other countries
H2: 0.1%
Gasoline: 99.9%</td></tr>
<tr><td rowspan="2">Diesel</td><td rowspan="2">Fuel cell train:
Diesel consumption for rail transport will be converted to H2</td><td colspan="3">Share of H_2/diesel for rail transport</td></tr>
<tr><td>H2: 5%
Diesel: 95%</td><td>H2: 10%
Diesel: 90%</td><td>H2: 20%
Diesel: 80%</td></tr>
</table>

OECD = Organisation for Economic Co-operation and Development.
Source: ERIA (2018).

2. Hydrogen Demand Potential (Phase 2)

This section re-analyses the hydrogen demand potential. The phase 2 study revised the scenarios for calculating hydrogen demand potential; more precisely, the study introduced a new idea to classify countries. Basic assumptions, other assumptions, and conversion factors in the phase 1 study were applied to phase 2.

2.1. Classification of East Asia Summit countries

Future hydrogen demand in a country is likely to be greatly affected by the balance between the hydrogen supply cost and the income level of a country. For instance, a resource-rich country could enjoy cheap hydrogen price whilst a resource-scarce country will accept a higher price that reflects the additional cost of import. In terms of income level, a high-income country can afford to pay for a higher price in exchange for environmental benefits whilst a low-income country cannot. In this way, the balance between the hydrogen supply price and the acceptable energy price range – in other words, the economic competitiveness or affordability of hydrogen – differs from country to country. And these facts would greatly affect the magnitude of market penetration of hydrogen in the future. Therefore, this study categorised the East Asia Summit (EAS) countries, excluding the United States (US), in two axes and four quadrants (Table 2.4).

Table 2.4: Classification of EAS Countries, excluding the United States

		Hydrogen Supply Cost	
		Cheap	**Expensive**
Income Level	**High**	**A** The hydrogen supply costs are low, and the income levels are high. **The most widespread use of hydrogen can be expected.** Australia Brunei Darussalam Indonesia Malaysia (Sabah and Sarawak) New Zealand	**B** The hydrogen supply costs are high, and the income levels are high as well. **The use of hydrogen can be expected through a hydrogen promotion policy.** China Japan Korea, Republic of Malaysia (Peninsula) Singapore Thailand
	Low	**C** The hydrogen supply costs are low, and the income levels are low as well. **The use of hydrogen is limited. Becomes a hydrogen exporter.** India Lao People's Democratic Republic Myanmar	**D** The hydrogen supply cost is high, and the income level is low. **Hydrogen demand is unlikely to be expected.** Cambodia Philippines Viet Nam

Source: Author.

2.2. Summary of Revised Scenarios (Phase 2)

Table 2.5 shows the revised assumptions and scenarios for calculating the hydrogen demand potential. The conversion ratio from conventional energy to hydrogen differs depending on the quadrant. Each quadrant has one conversion ratio to avoid evaluation complexity.

Table 2.5: Assumptions and Scenarios for Calculating Hydrogen Demand Potential (Phase 2)

Quadrant A

Sector	Assumption	Conversion Ratio
Electricity generation	Full-scale hydrogen use will begin in 2030 (Assume that 10 years will be required to build a large-scale hydrogen production plant, domestic supply infrastructure, and hydrogen-fired CCGT.) Hydrogen will be supplied to the power plant through newly constructed hydrogen pipelines.	The ratio of conversion to hydrogen and natural gas mixed fuel or pure hydrogen. 50%
	Existing natural gas power generation (TWh) as of 2030 will be partially converted to the 30% hydrogen and 70% natural gas mixed fuel by replacing the combustors.	
	New natural gas power generation (TWh) after 2030 will be partially converted to the 100% hydrogen fuel.	
Transport	Assume a certain share of the zero-emission vehicle (ZEV) in the registered passenger cars in 2040. Fuel cell vehicle (FCV) share in ZEV: 20%	The ratio of ZEV; 50%

CCGT = combined cycle gas turbine.

Quadrant B

Sector	Assumption	Conversion Ratio
Electricity generation (Existing generation)	Full-scale hydrogen use will begin in 2030 (Assume that 10 years will be required to build a large-scale hydrogen production plant, domestic supply infrastructure, and hydrogen-fired CCGT.) Japan, the Republic of Korea, Malaysia (Peninsula), Singapore, and Thailand are assumed to construct hydrogen import terminals adjacent to liquefied natural gas (LNG) import terminals for power generation. Other than Singapore, existing gas pipelines will be used to distribute hydrogen in a country. If gas power plants are connected to the same gas pipeline network, they will be converted to hydrogen at once	The ratio of conversion to hydrogen and natural gas mixed fuel or pure hydrogen
	Existing natural gas power generation (TWh) as of 2030 will be partially converted to the 30% hydrogen and 70% natural gas mixed fuel by replacing the combustors.	
	Malaysia (Peninsula) Imported hydrogen.	50%
	Thailand Gas power plants connected to LNG import terminals will be converted. The gas power plants in the following two areas are not subject to conversion: – The south-eastern area that receives natural gas from the JDA with Malaysia, – The north-western area that natural gas is imported from Myanmar.	50%
	China China will have a mix of domestic fossil–fuel reformed hydrogen and imported hydrogen.	50%
	Japan Imported hydrogen	50%
	Republic of Korea The KOGAS high-pressure gas pipeline connected to the gas-fired plants is looped.	100%
	Singapore The country is small. It is assumed that a new hydrogen pipeline will be constructed. The number	100%

	of gas-fired plants may be very small.	
Electricity generation (New generation)	New natural gas power generation (TWh) after 2030 will be partially converted to the 100% hydrogen fuel. Japan, the Republic of Korea Singapore, and Thailand are assumed to construct new 100% hydrogen thermal power adjacent to the hydrogen import terminals, which will not be connected to the existing natural gas pipelines. China will have a mix of domestic fossil fuel–reformed hydrogen and imported hydrogen.	
	Malaysia (Peninsula) **Thailand** **China** **Japan** **Republic of Korea**	50%
	Singapore The number of gas-fired plants may be very small.	100%
Transport	Assume a certain share of the zero-emission vehicle (ZEV) in the registered passenger cars in 2040. FCV share in ZEV: 10%	The ratio of ZEV 30%

CCGT = combined cycle gas turbine, JDA = joint development area of offshore hydrocarbon field, LNG = liquefied natural gas.

Quadrant C

Sector	Assumption	Conversion Ratio
Electricity generation	Full-scale hydrogen use will begin in 2040 (assume it will take 20 years to improve income levels) Hydrogen is supplied to the power plant through newly constructed hydrogen pipelines.	The ratio of conversion to mixed fuel
	Existing natural gas–fired electricity generation (TWh) as of 2030 will be partially converted to the 30% hydrogen and 70% natural gas–mixed fuel by replacing the combustors except for the Lao PDR that has no plan of introducing natural gas–fired plant.	30%
	A new 100% hydrogen-fired plant will be operated in 2040 except for the Lao PDR. The generation capacity is assumed to be 200 MW.	One 200 MW plant
Transport	Assume a certain share of the zero-emission vehicle (ZEV) in the registered passenger cars in 2040. FCV share in ZEV: 10%	The ratio of ZEV 30%

Quadrant D

Sector	Assumption	Conversion Ratio
Electricity generation	Full-scale hydrogen use will begin in 2040 (Assume it will take 20 years to improve income levels). As of 2040, a pilot project or first plant will be introduced. Assume that a hydrogen import terminal will be constructed adjacent to the liquefied natural gas (LNG) terminal that is expected to be developed in the future. Cambodia will also consider importing hydrogen from the Lao PDR through pipelines.	
(Existing generation)	Existing natural gas power generation (TWh) as of 2030 will be partially converted to the 30% hydrogen and 70% natural gas mixed fuel by replacing the combustors.	
	Viet Nam	30%
	Cambodia Philippines The number of gas-fired plants may be very small.	100%
(New generation)	No new 100% hydrogen-fired plant will be operated in 2040.	–
Transport	Assume a certain share of the zero-emission vehicle (ZEV) in the registered passenger cars in 2040. FCV share in ZEV: 5%	The ratio of ZEV 30%

Source: Author.

Table 2.6, Figure 2.1, and Figure 2.2 show the major differences of scenarios between phases 1 and 2.

In the electricity generation sector, coal electricity generation is excluded because the gradual phase-out of the coal electricity generation scenario was already included in the ERIA energy outlook 2019. The conversion ratio from natural gas electricity generation to hydrogen is increased. In phase 1, only new power generation was the subject of fuel switch to hydrogen but, in phase 2, existing power generation was also targeted to use hydrogen. In addition, after 2030, we assumed that pure hydrogen thermal electricity generation would start operation considering recent developments in technology.

Meanwhile, hydrogen consumption in the industry sector is excluded. We thought it would be premature to build pure hydrogen pipeline infrastructures for industrial boilers before 2040. This is because of a smaller demand per plant compared to electricity generation, which makes feasibility of a pure hydrogen pipeline low.

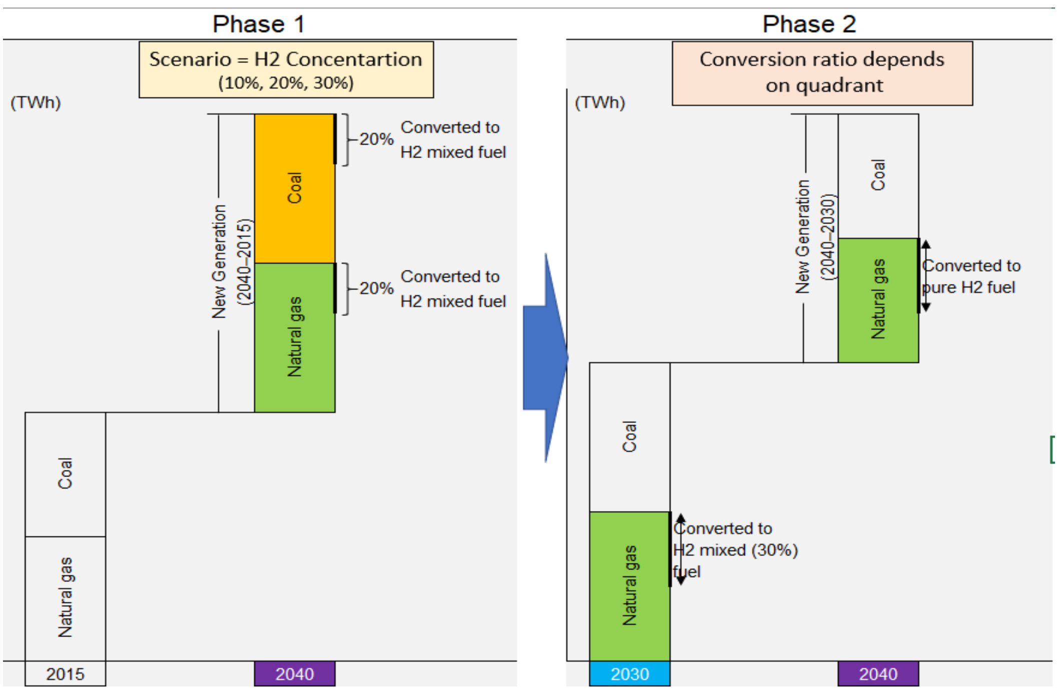
In the transport sector, diesel was excluded because calculated hydrogen demand to substitute for diesel engine was very small in phase 1. The transport sector's scenarios in phase 2 are not progressive compared to phase 1.

Table 2.6: Major Differences of Scenarios between Phases 1 and 2

Sector	Item	Phase 1	Phase 2
Electricity generation	Subject of fuel switch	Natural gas Coal	Natural gas
	Scenario (Factors of change)	Fuel for electricity generation: The hydrogen concentration in natural gas and hydrogen mixed fuel	Generated electricity: The conversion ratio of generated electricity to hydrogen/natural gas mixed fuel or pure hydrogen
Industry	Subject of fuel switch	Natural gas	Excluded
Transport	Mode	Passenger fuel cell vehicle (gasoline) Fuel cell bus (diesel) Fuel cell train (diesel)	Passenger fuel cell vehicle (gasoline)
	Scenario	Conversion ratio of gasoline/diesel	The ratio of zero-emission vehicle

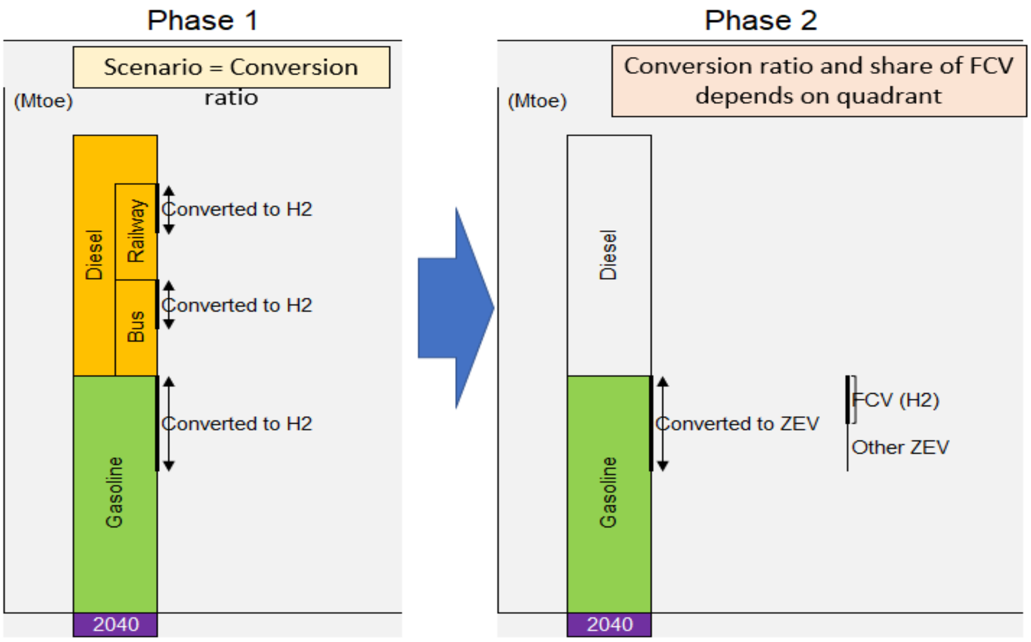
Source: Author.

Figure 2.1: Hydrogen Demand Calculation Method of the Electricity Generation Sector



Note: Scale is not accurate.
Source: Author.

Figure 2.2: Hydrogen Demand Calculation Method of the Transport Sector



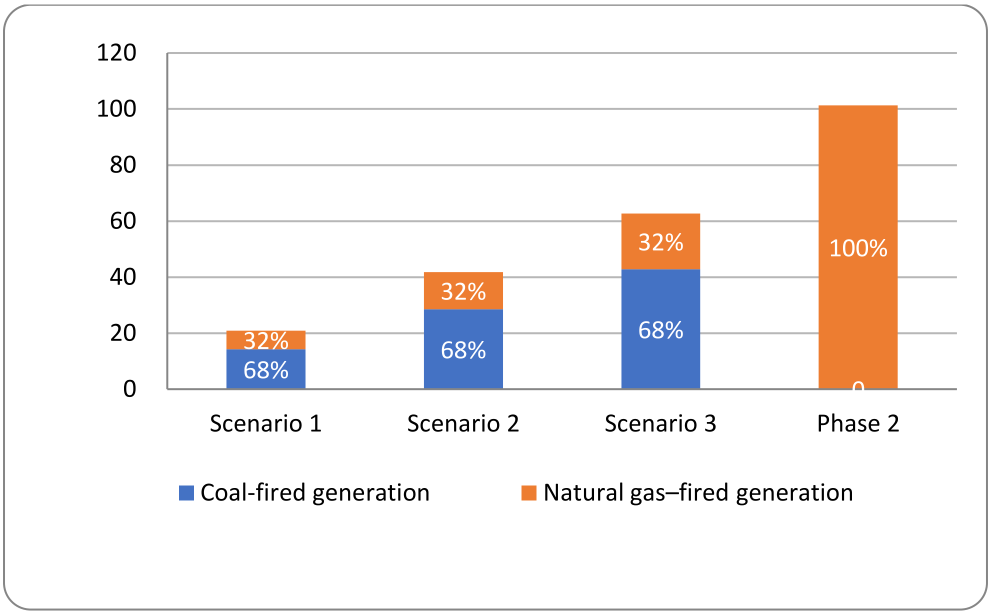
FCV = fuel cell vehicle, ZEV = zero-emission vehicle.
Note: Scale is not accurate.
Source: Author.

2.3. Hydrogen demand potential by sector and by country (Phase 2)

2.3.1. Electricity generation sector

Figure 2.3 shows the hydrogen demand potential of the electricity generation sector of the EAS in 2040. In the phase 2 study, hydrogen demand potential will reach 101 Mtoe. Compared to phase 1, hydrogen demand potential will increase 80 Mtoe from scenario 1, 59 Mtoe from scenario 2, and 38 Mtoe from scenario 3, despite coal-fired electricity generation being excluded in phase 2.

Figure 2.3: Hydrogen Demand Potential of the Electricity Generation Sector in the EAS in 2040



Source: Author.

Table 2.7 compares the scenarios of the electricity generation sector between the two study phases.

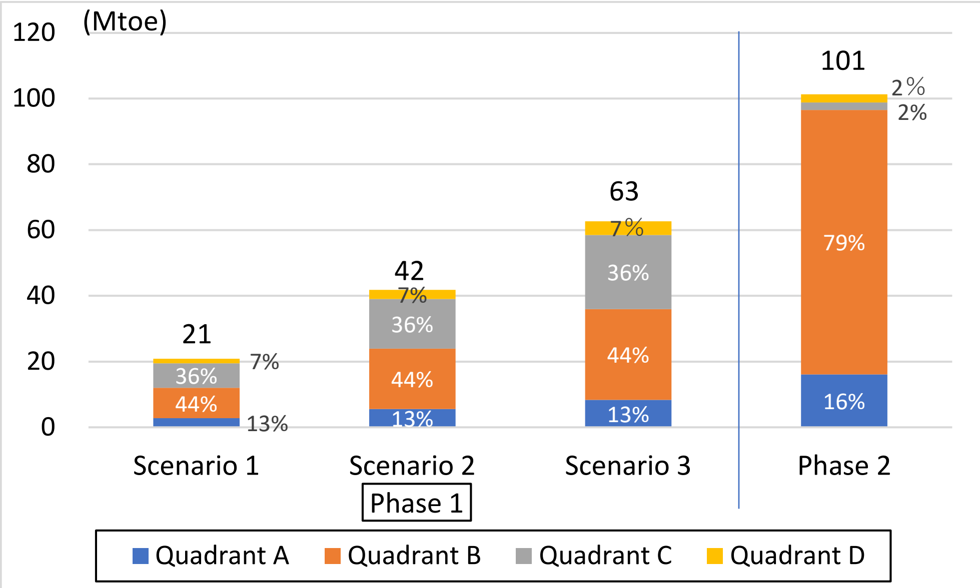
Table 2.7: Comparison of Scenarios in the Electricity Generation Sector

Item	Phase 1	Phase 2
Converted electricity generation (Natural gas)	New	Existing and new
Conversion ratio	20%	30%, 50%, 100% (Depends on the quadrant)
Hydrogen content in the mixed fuel	Three scenarios (10%, 20%, 30%)	Existing 30% New 100%

Source: Author.

Figure 2.4 shows the hydrogen demand potential of the electricity generation sector in 2040, by quadrant. Compared to the phase 1 study, hydrogen demand potential increases in quadrants A and B. However, it decreases in quadrants C and D. The difference comes from a different expectation for natural electricity generation. In quadrants A and B, countries are expected to generate a large capacity of natural gas electricity. Meanwhile in quadrants C and D, countries are expected to generate a larger capacity of coal electricity rather than natural gas.

Figure 2.4: Hydrogen Demand Potential of the Electricity Generation Sector in the EAS, by Quadrant



EAS = East Asia Summit.
Source: Author.

Table 2.8 shows electricity generation from coal and natural gas, which is the basis of the calculation of hydrogen demand potential, and their share to total electricity generation. The latter is a reference to make comparison easier.

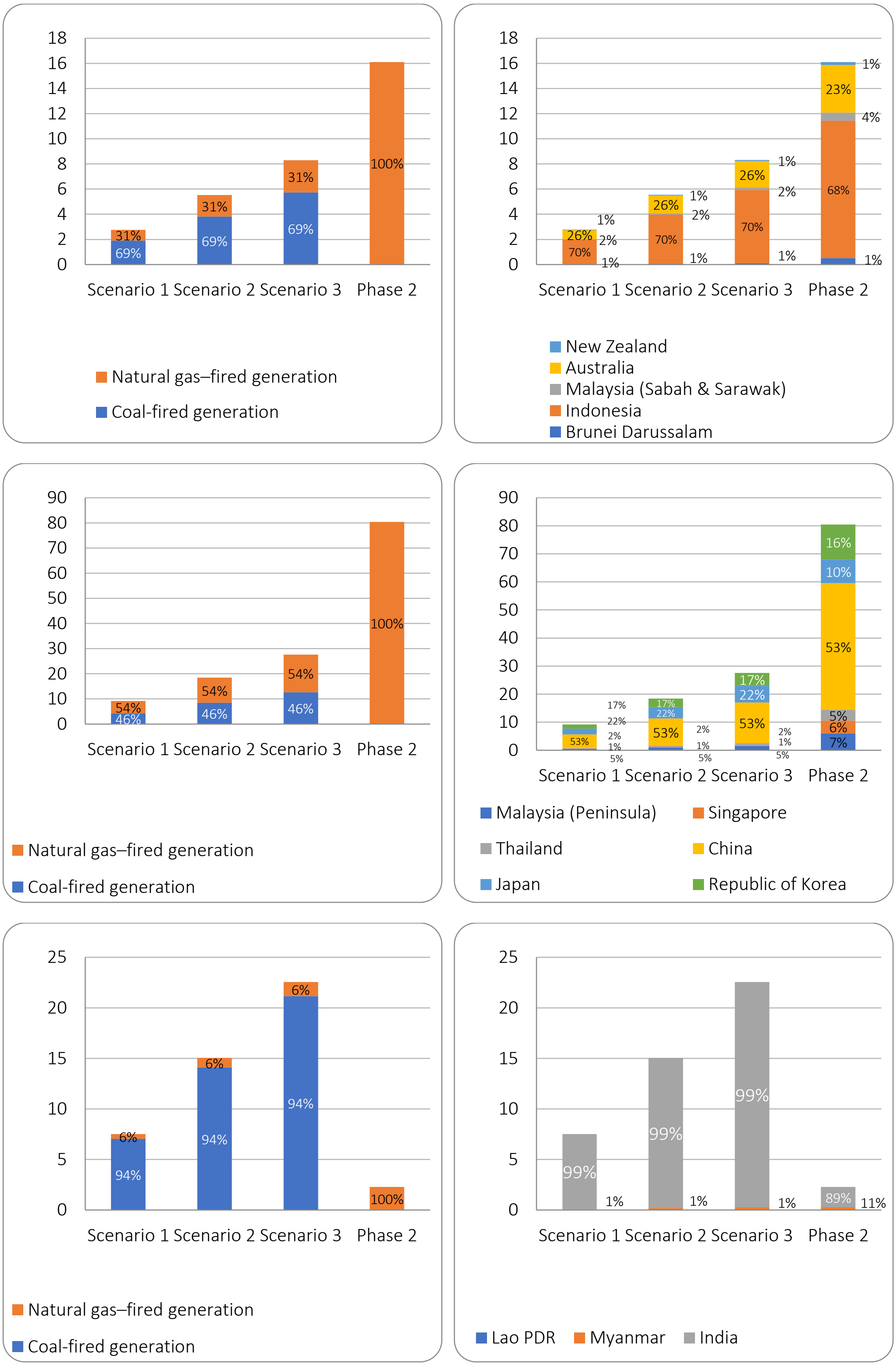
Table 2.8: Electricity Generation from Coal and Natural Gas, by Country

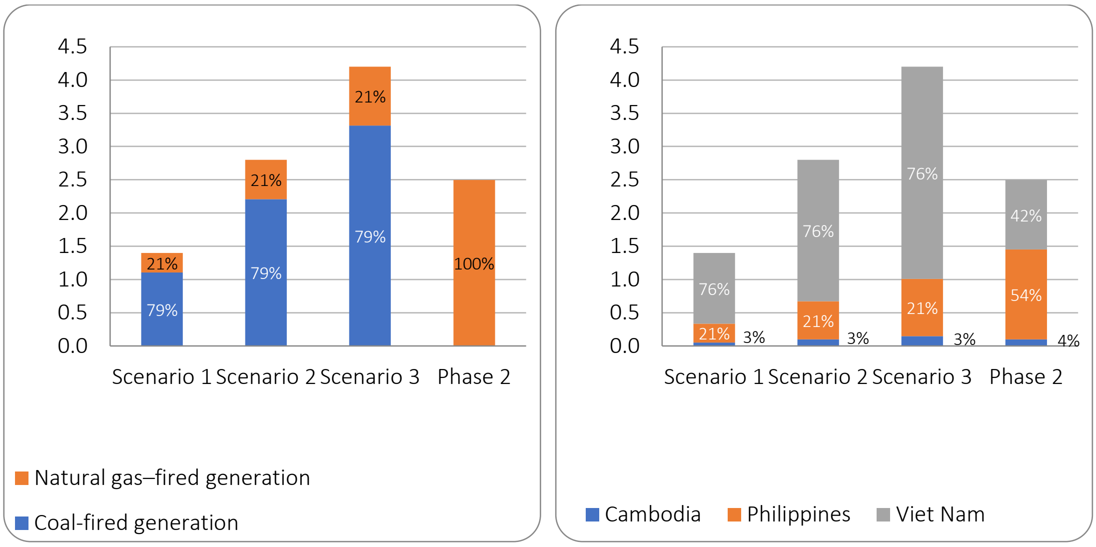
Country	Electricity Generation (TWh)				Share, %			
	Phase 1		Phase 2		Coal		Natural Gas	
	Coal	Natural Gas	Natural Gas	Natural Gas				
	New	New	Existing	New	2015	2040	2015	2040
Brunei Darussalam	4	10	9	5	–	21	99	79
Indonesia	551	161	86	134	56	70	25	23
Malaysia (Sabah and Sarawak)	4	12	13	6	10	10	24	26
Australia	141	119	90	28	63	38	21	32
New Zealand	0	10	10	1	4	0	16	18
Quadrant A	700	312	208	174	52	56	23	26
Malaysia (Peninsula)	78	109	121	52	50	47	52	58
Singapore	1	38	74	11	1	1	95	91
Thailand	39	44	151	10	20	24	71	55
China	780	994	683	456	70	49	2	11
Japan	337	390	381	9	33	29	40	34
Republic of Korea	309	256	181	74	43	42	22	34
Quadrant B	1,544	1,831	1,591	613	62	45	12	17
Lao PDR	43	–	–	–	13	63	0	0
Myanmar	27	7	9	4	0	42	41	22
India	2,557	162	154	77	75	75	5	5
Quadrant C	2,627	169	163	81	74	74	5	5
Cambodia	11	7	2	5	48	34	0	18
Philippines	68	37	33	23	45	49	23	26
Viet Nam	325	65	85	25	32	69	28	20
Quadrant D	405	109	120	52	36	62	26	22
Total	5,275	2,421	2,083	920	62	54	12	15

Note: Malaysia is divided by generation capacity.
The definition of 'New generation' is different between phases 1 and 2 of the study.
Source: Author.

Figure 2.5 shows the hydrogen demand potential in 2040 by generation fuel and by country.

Figure 2.5: Hydrogen Demand Potential of the Electricity Generation Sector, by Country



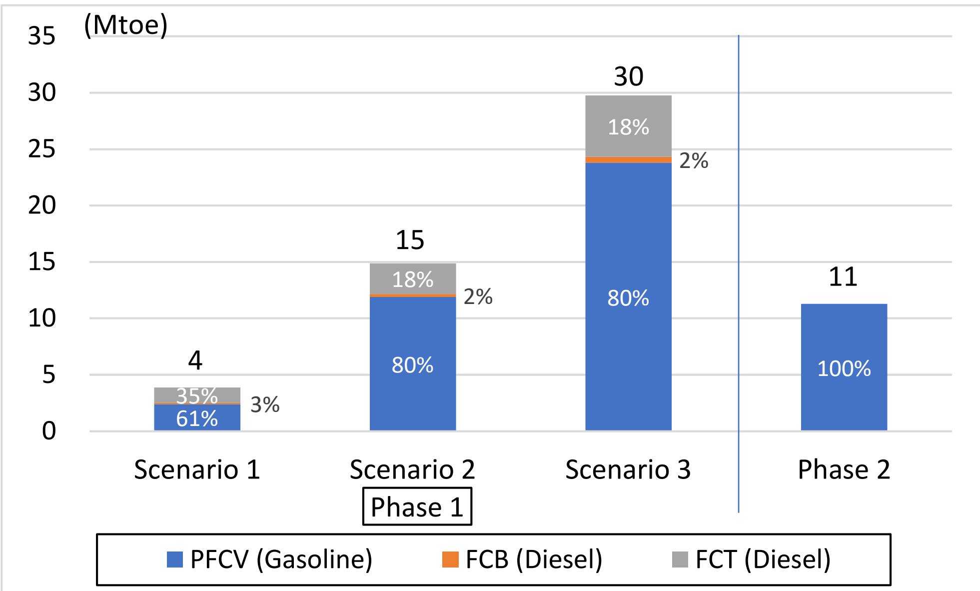


Note: Malaysia is divided by natural gas generation capacity.
Source: Author.

2.3.1. Transport sector

Figure 2.6 shows the hydrogen demand potential of the transport sector of the EAS in 2040. In the phase 2 study, hydrogen demand potential will reach 11 Mtoe. Compared to phase 1, hydrogen demand potential will increase 7 Mtoe from scenario 1 but will decrease 4 Mtoe from scenario 2 and 19 Mtoe from scenario 3.

Figure 2.6: Hydrogen Demand Potential of the Transport Sector in the EAS in 2040



Note: PFCV = passenger fuel cell vehicle, FCB = fuel cell bus, FCT = fuel cell train.
Source: Author.

Table 2.9 compares the scenarios in the transport sector between the two study phases.

Table 2.9: Comparison of Scenarios in the Transport Sector

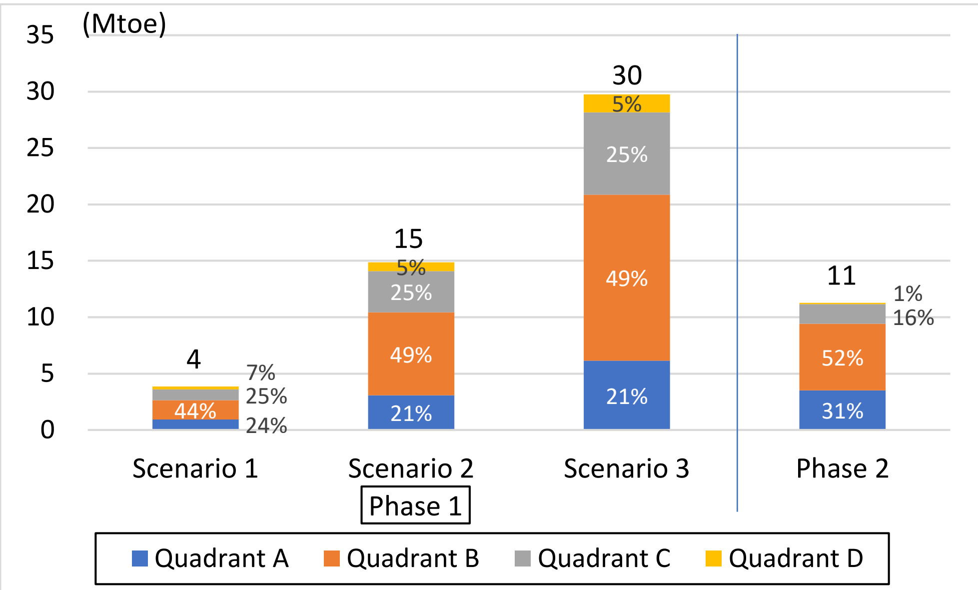
Item	Phase 1	Phase 2
Mode	Passenger vehicle Bus Railway	Passenger vehicle
Conversion ratio	Ratio: Depends on country Passenger: From 1% to 20% Bus: From 0.025% to 0.2% Railway: From 5% to 20%	1.5%, 3%, 10% (Depends on quadrant)

Source: Author.

Figure 2.7 shows the hydrogen demand potential of the transport sector in 2040, by quadrant.

Compared to the phase 1 study, hydrogen demand in quadrant A countries will increase 2.6 Mtoe from scenario 1, 0.4 Mtoe from scenario 2, but will decrease 2.6 Mtoe from scenario 3. Quadrant B will increase 4.2 Mtoe from scenario 1 but will decrease 1.4 Mtoe from scenario 2 and 8.8 Mtoe from scenario 3. Quadrant C will increase 0.8 Mtoe from scenario 1 but will decrease 1.9 Mtoe from scenario 2 and 5.6 Mtoe from scenario 3. Quadrant D will decrease 0.2 Mtoe from scenario 1, 0.7 Mtoe from scenario 2, and 1.5 Mtoe from scenario 3.

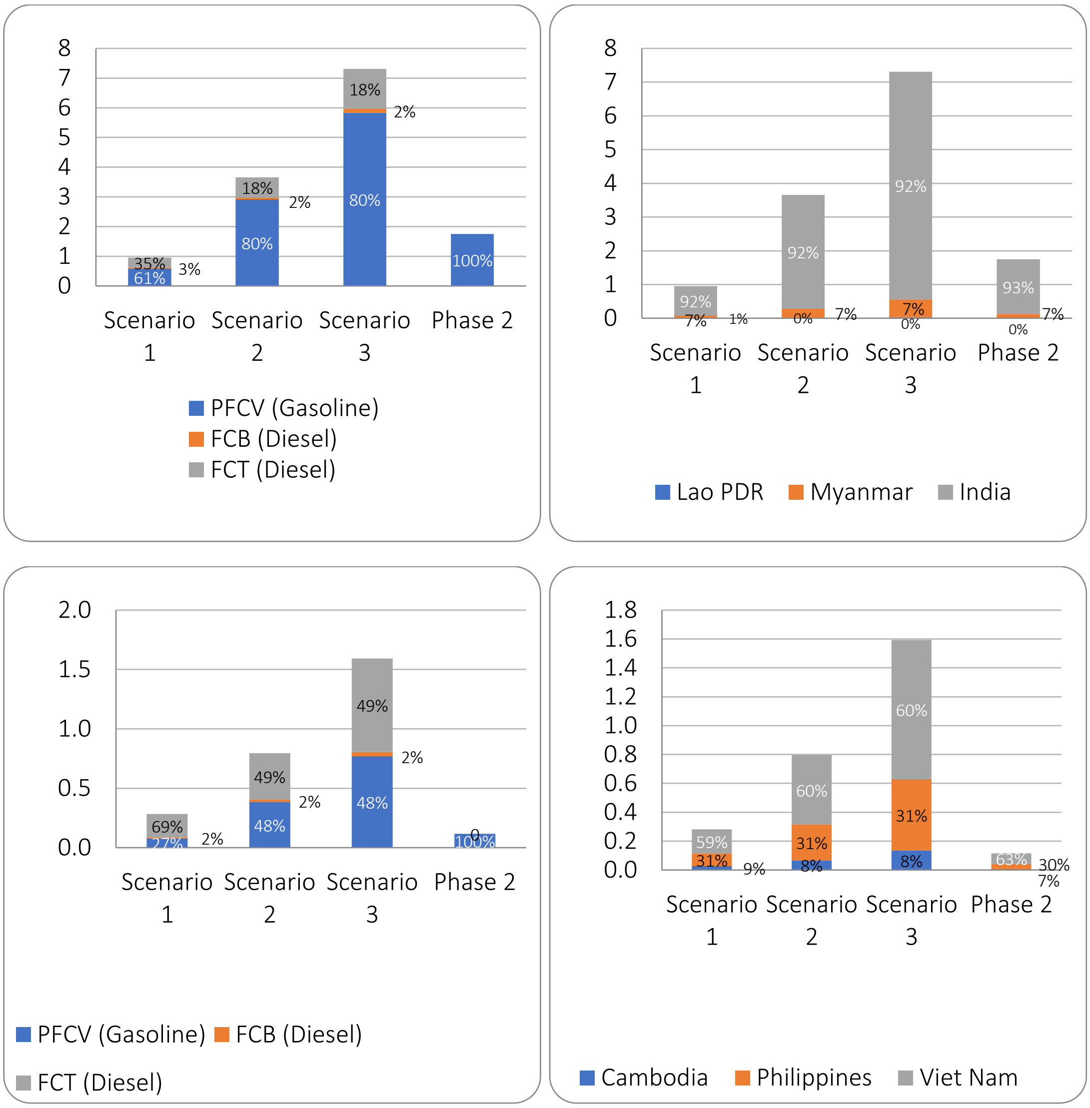
Figure 2.7: Hydrogen Demand Potential of the Transport Sector in the EAS, by Quadrant



EAS = East Asia Summit.
Source: Author.

Figure 2.8 shows the hydrogen demand potential in 2040 by transport mode and by country.

Figure 2.8: Hydrogen Demand Potential of the Transport Sector, by Country and Transport Mode



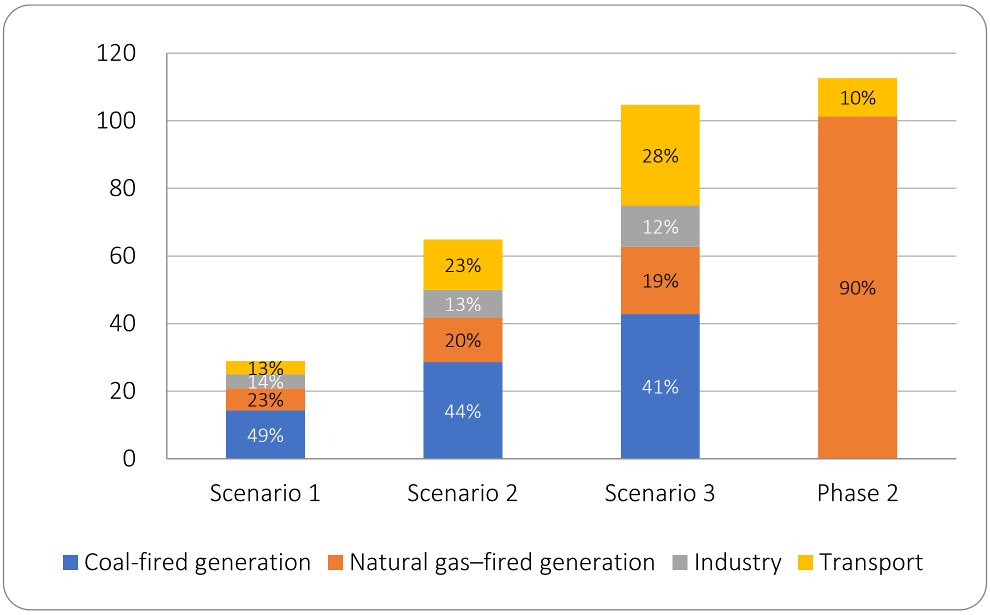
PFCV = passenger fuel cell vehicle, FCB = fuel cell bus, FCT = fuel cell train.
Note: Malaysia is divided by state GDP in 2018.
Source: Author.

2.3.3. Total hydrogen demand potential

Figure 2.9 shows the total hydrogen demand potential of the EAS in 2040. In the phase 1 study, hydrogen demand potential in the industry sector was included, which are 4 Mtoe in scenario 1, 8 Mtoe in scenario 2, and 12 Mtoe in scenario 3. However, it was excluded in phase 2.

In phase 2, total hydrogen demand potential will reach 113 Mtoe. Compared to phase 1, total hydrogen demand potential will increase by 84 Mtoe from scenario 1, 48 Mtoe from scenario 2, and 8 Mtoe from scenario 3.

Figure 2.9: Total Hydrogen Demand Potential in the EAS in 2040

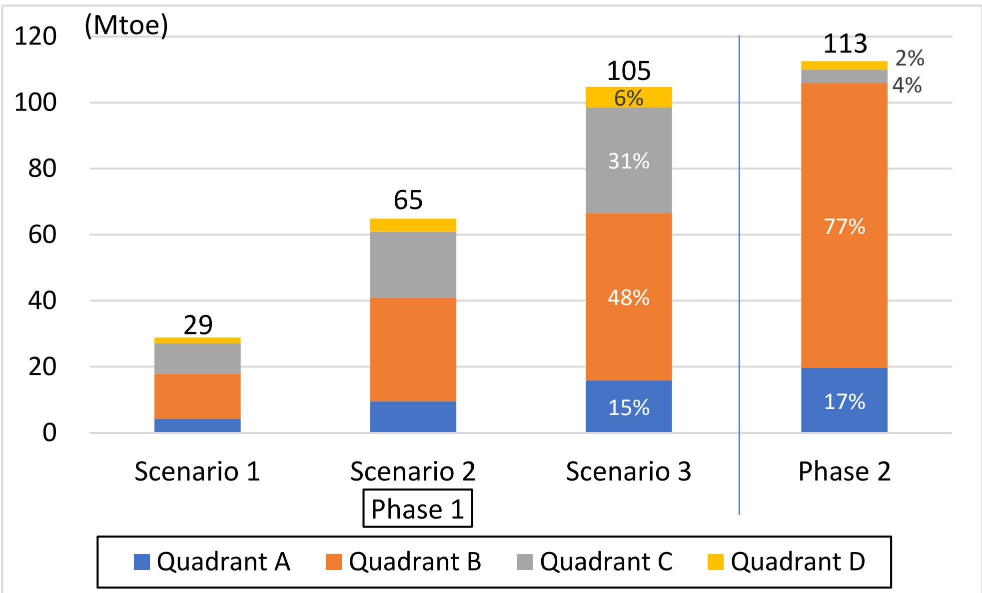


Source: Author.

Figure 2.10 shows the total hydrogen demand potential in 2040 by quadrant.

Compared to the phase 1 study, quadrant A will increase 15 Mtoe from scenario 1, 10 Mtoe from scenario 2, and 4 Mtoe from scenario 3. Quadrant B will increase 73 Mtoe from scenario 1, 55 Mtoe from scenario 2, and 36 Mtoe from scenario 3. Quadrant C will decrease 5 Mtoe from scenario 1, 16 Mtoe from scenario 2, and 28 Mtoe from scenario 3. Quadrant D will decrease 1 Mtoe from scenario 1 but will decrease 1 Mtoe from scenario 2 and 4 Mtoe from scenario 3.

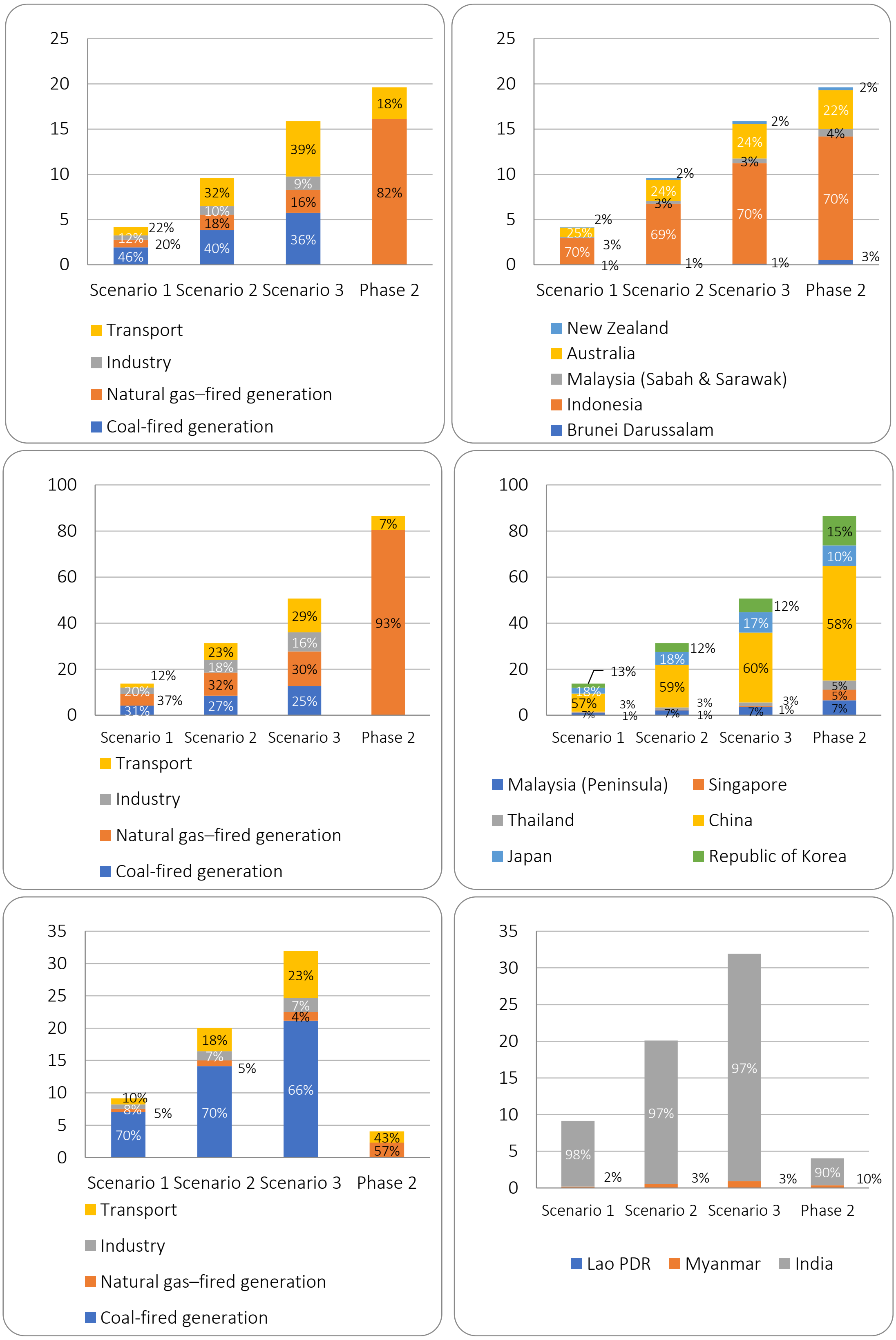
Figure 2.10: Total Hydrogen Demand Potential in the EAS in 2040, by Quadrant

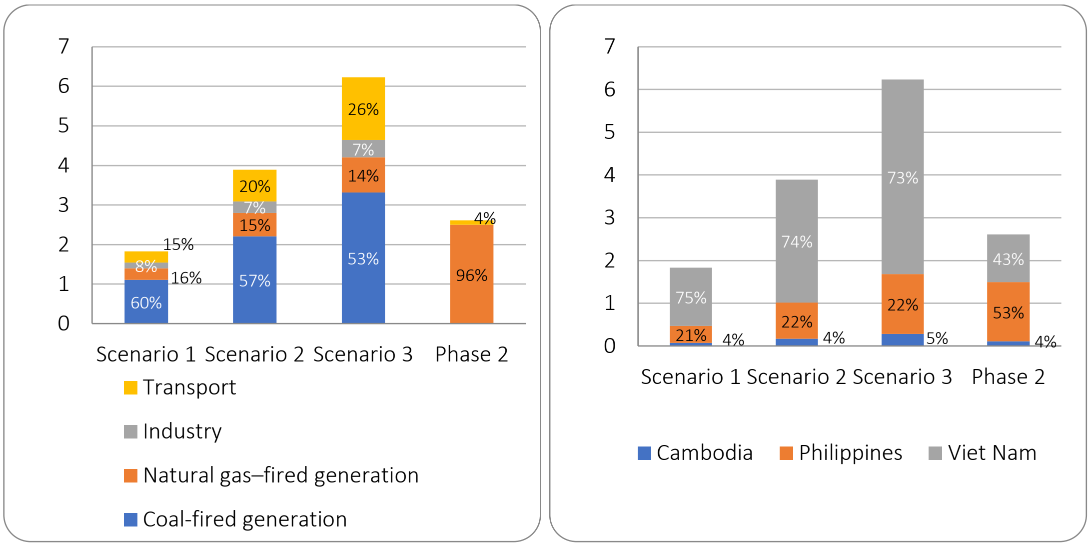


Source: Author.

Figure 2.11 shows the total hydrogen demand potential in 2040 by sector and by country.

Figure 2.11: Total Hydrogen Demand Potential, by Country and Sector





Gen = generation.
Source: Author.

2.4. Replaced energy

Table 2.10 shows the electricity generation sector's replaced energy by hydrogen in 2040. In the phase 1 study, net natural gas demand increased in many countries because it assumed 20% of coal-fired electricity generation to be replaced by natural gas and hydrogen mixed fuel-fired electricity generation.

Table 2.10: Replaced Energy by Hydrogen in the Electricity Generation Sector in 2040

Unit: Mtoe

	Phase 1											Phase 2
Generation	Coal Fired				Natural Gas Fired			Coal Fired + Natural Gas Fired				Natural Gas Fired
Fuel	Replaced coal	New natural gas demand			Replaced natural gas			Replaced coal	Net natural gas increase			Replaced natural gas
Scenario	S1, S2, S3	S1	S2	S3	S1	S2	S3	S1, S2, S3	S1	S2	S3	-
Brunei Darussalam	-0.1	0.1	0.1	0.1	-0.0	-0.1	-0.1	-0.1	0.1	0.0	-0.0	-0.5
Indonesia	-9.5	13.5	12.0	10.5	-0.4	-0.9	-1.3	-9.5	13.1	11.2	9.2	-10.9
Malaysia	-0.1	0.1	0.1	0.1	-0.0	-0.1	-0.1	-0.1	0.1	0.0	-0.0	-0.7
Australia	-2.4	3.5	3.1	2.7	-0.3	-0.6	-1.0	-2.4	3.2	2.4	1.7	-3.8
New Zealand	0.0	0.0	0.0	0.0	-0.0	-0.1	-0.1	0.0	-0.0	-0.1	-0.1	-0.2
Quadrant A	-12.0	17.2	15.3	13.4	-0.9	-1.7	-2.6	-12.0	16.3	13.6	10.8	-16.1
Malaysia	-1.3	1.9	1.7	1.5	-0.3	-0.6	-0.9	-1.3	1.6	1.1	0.6	-6.0
Singapore	-0.0	0.0	0.0	0.0	-0.1	-0.2	-0.3	-0.0	-0.1	-0.2	-0.3	-4.6
Thailand	-0.7	1.0	0.8	0.7	-0.1	-0.2	-0.4	-0.7	0.8	0.6	0.4	-3.8
China	-13.4	19.2	17.0	14.9	-2.7	-5.4	-8.1	-13.4	16.5	11.6	6.8	-45.1
Japan	-5.8	8.3	7.4	6.4	-1.1	-2.1	-3.2	-5.8	7.2	5.2	3.3	-8.4
Republic of Korea	-5.3	7.6	6.7	5.9	-0.7	-1.4	-2.1	-5.3	6.9	5.3	3.8	-12.5
Quadrant B	-26.6	37.9	33.7	29.5	-5.0	-10.0	-15.0	-26.6	32.9	23.7	14.5	-80.4
Lao PDR	-	-	-	-	-	-	-	-	-	-	-	-
Myanmar	-0.5	0.7	0.6	0.5	-0.0	-0.0	-0.1	-0.5	0.6	0.5	0.4	-0.3
India	-44.0	62.8	55.9	48.9	-0.4	-0.9	-1.3	-44.0	62.4	55.0	47.5	-2.0
Quadrant C	-44.4	63.5	56.4	49.4	-0.5	-0.5	-0.5	-44.4	63.0	55.5	48.0	-2.3
Cambodia	-0.2	0.3	0.2	0.2	-0.0	-0.0	-0.1	-0.2	0.2	0.2	0.2	-0.1
Philippines	-1.2	1.7	1.5	1.3	-0.1	-0.2	-0.3	-1.2	1.6	1.3	1.0	-1.4
Viet Nam	-5.6	8.0	7.1	6.2	-0.2	-0.4	-0.5	-5.6	7.8	6.8	5.7	-1.0
Quadrant D	-7.0	9.9	8.8	7.7	-0.3	-0.3	-0.3	-7.0	9.6	8.2	6.8	-2.5
Total	-90.0	128.6	114.3	100.0	-6.6	-12.5	-18.3	-90.0	122.0	101.1	80.2	-101.3

Notes: S1 = scenario 1, S2 = scenario 2, S3 = scenario 3; Negative number = decrease of demand, Positive number = increase of demand; Malaysia is divided by generation capacity.
Source: Author.

Table 2.11 shows the industry sector's replaced energy by hydrogen in 2040. In the phase 2 study, the industry sector was not included to calculate hydrogen demand potential.

Table 2.11: Replaced Energy by Hydrogen in the Industry Sector in 2040

Unit: Mtoe

	Phase 1			Phase 2
Fuel	**Replaced Natural Gas**			**-**
Scenario	Scenario 1	Scenario 2	Scenario 3	-
Brunei Darussalam	-	-	-	-
Indonesia	-0.3	-0.5	-0.8	-
Malaysia (Sabah & Sarawak)	-0.0	-0.1	-0.1	-
Australia	-0.2	-0.3	-0.5	-
New Zealand	-0.0	-0.0	-0.1	-
Quadrant A	-0.5	-1.0	-1.5	-
Malaysia (Peninsula)	-0.2	-0.4	-0.7	-
Singapore	-0.0	-0.1	-0.1	-
Thailand	-0.2	-0.4	-0.6	-
China	-1.8	-3.6	-5.4	-
Japan	-0.3	-0.6	-0.9	-
Republic of Korea	-0.2	-0.4	-0.7	-
Quadrant B	-2.8	-5.5	-8.3	-
Lao PDR	-	-	-	-
Myanmar	-0.0	-0.1	-0.1	-
India	-0.7	-1.3	-2.0	-
Quadrant C	-0.7	-1.4	-2.1	-
Cambodia	-	-	-	-
Philippines	-0.0	-0.0	-0.0	-
Viet Nam	-0.1	-0.3	-0.4	-
Quadrant D	-0.1	-0.3	-0.4	-
Total	**-4.1**	**-8.2**	**-12.3**	**-**

Note: Malaysia is divided by state GDP in 2018.
Source: Author.

Table 2.12 shows the transport sector's replaced energy by hydrogen in 2040. In the phase 2 study, diesel demand (bus and railway) was not included to calculate hydrogen demand potential.

The fuel economy of FCVs was assumed to be 2.7 times better than gasoline vehicles. (Please see the phase 1 study.)

Table 2.12: Replaced Energy by Hydrogen in the Transport Sector in 2040

Unit: Mtoe

	Phase 1						Phase 2
Replaced Fuel	**Gasoline**			**Diesel**			**Gasoline**
Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3	-
Brunei Darussalam	-0.0	-0.0	-0.1	-0.0	-0.0	-0.0	-0.1
Indonesia	-0.7	-3.7	-7.4	-0.4	-0.9	-1.8	-7.4
Malaysia (Sabah & Sarawak)	-0.0	-0.2	-0.5	-0.0	-0.0	-0.1	-0.5
Australia	-0.3	-1.3	-2.6	-0.1	-0.1	-0.2	-1.3
New Zealand	-0.0	-0.2	-0.4	-0.0	-0.0	-0.0	-0.2
Quadrant A	-1.1	-5.5	-11.0	-0.5	-1.0	-2.1	-9.4
Malaysia (Peninsula)	-0.2	-1.2	-2.5	-0.1	-0.2	-0.3	-1.2
Singapore	-0.0	-0.0	-0.1	-0.0	-0.0	-0.0	-0.0
Thailand	-0.1	-0.4	-0.9	-0.0	-0.0	-0.0	-0.4
China	-2.5	-12.5	-25.0	-0.3	-0.6	-1.1	-12.5
Japan	-0.5	-2.6	-5.2	-0.0	-0.0	-0.1	-1.3
Republic of Korea	-0.2	-0.9	-1.7	-0.0	-0.0	-0.0	-0.4
Quadrant B	-3.5	-17.7	-35.4	-0.4	-0.8	-1.6	-16.0
Lao PDR	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0
Myanmar	-0.1	-0.6	-1.1	-0.0	-0.1	-0.1	-0.3
India	-1.5	-7.3	-14.6	-0.3	-0.7	-1.4	-4.4
Quadrant C	-1.6	-7.9	-15.8	-0.4	-0.7	-1.5	-4.7
Cambodia	-0.0	-0.1	-0.1	-0.0	-0.0	-0.1	-0.0
Philippines	-0.1	-0.3	-0.6	-0.1	-0.1	-0.3	-0.1
Viet Nam	-0.1	-0.7	-1.3	-0.1	-0.2	-0.5	-0.2
Quadrant D	-0.2	-1.0	-2.1	-0.2	-0.4	-0.8	-0.3
Total	**-6.4**	**-32.1**	**-64.2**	**-1.5**	**-3.0**	**-6.0**	**-30.5**

Note: Malaysia is divided by state GDP in 2018.

Source: Author.

Table 2.13 shows the total replaced energy by hydrogen in 2040.

Table 2.13: Total Replaced Energy by Hydrogen in 2040

Unit: Mtoe

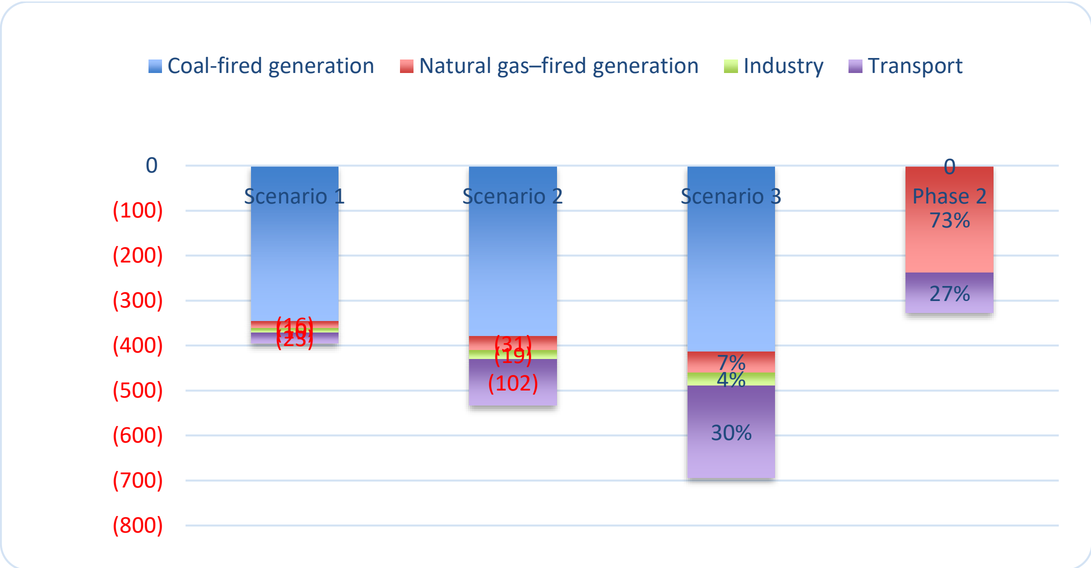
	Phase 1										Phase 2	
Replaced Fuel	**Coal**	**Natural Gas**			**Gasoline**			**Diesel**			**Natural Gas**	**Gasoline**
Scenario	S1, S2, S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	-	-
Brunei Darussalam	-0.1	0.1	0.0	-0.0	-0.0	-0.0	-0.1	-0.0	-0.0	-0.0	-0.5	-0.1
Indonesia	-9.5	12.8	10.6	8.4	-0.7	-3.7	-7.4	-0.4	-0.9	-1.8	-10.9	-7.4
Malaysia	-0.1	0.0	-0.1	-0.2	-0.0	-0.2	-0.5	-0.0	-0.0	-0.1	-0.7	-0.5
Australia	-2.4	3.0	2.1	1.2	-0.3	-1.3	-2.6	-0.1	-0.1	-0.2	-3.8	-1.3
New Zealand	0.0	-0.1	-0.1	-0.2	-0.0	-0.2	-0.4	-0.0	-0.0	-0.0	-0.2	-0.2
Quadrant A	-12.0	15.9	12.6	9.4	-1.1	-5.5	-11.0	-0.5	-1.0	-2.1	-16.1	-9.4
Malaysia	-1.3	1.4	0.7	-0.1	-0.2	-1.2	-2.5	-0.1	-0.2	-0.3	-6.0	-1.2
Singapore	-0.0	-0.1	-0.3	-0.4	-0.0	-0.0	-0.1	-0.0	-0.0	-0.0	-4.6	-0.0
Thailand	-0.7	0.6	0.2	-0.2	-0.1	-0.4	-0.9	-0.0	-0.0	-0.0	-3.8	-0.4
China	-13.4	14.7	8.0	1.4	-2.5	-12.5	-25.0	-0.3	-0.6	-1.1	-45.1	-12.5
Japan	-5.8	6.9	4.6	2.3	-0.5	-2.6	-5.2	-0.0	-0.0	-0.1	-8.4	-1.3
Republic of Korea	-5.3	6.7	4.9	3.1	-0.2	-0.9	-1.7	-0.0	-0.0	-0.0	-12.5	-0.4
Quadrant B	-26.6	30.2	18.2	6.2	-3.5	-17.7	-35.4	-0.4	-0.8	-1.6	-80.4	-16.0
Lao PDR	-	-	-	-	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-	-0.0
Myanmar	-0.5	0.6	0.5	0.3	-0.1	-0.6	-1.1	-0.0	-0.1	-0.1	-0.3	-0.3
India	-44.0	61.7	53.6	45.6	-1.5	-7.3	-14.6	-0.3	-0.7	-1.4	-2.0	-4.4
Quadrant C	-44.4	62.3	54.1	45.9	-1.6	-7.9	-15.8	-0.4	-0.7	-1.5	-2.3	-4.7
Cambodia	-0.2	0.2	0.2	0.2	-0.0	-0.1	-0.1	-0.0	-0.0	-0.1	-0.1	-0.0
Philippines	-1.2	1.6	1.3	1.0	-0.1	-0.3	-0.6	-0.1	-0.1	-0.3	-1.4	-0.1
Viet Nam	-5.6	7.7	6.5	5.3	-0.1	-0.7	-1.3	-0.1	-0.2	-0.5	-1.0	-0.2
Quadrant D	-7.0	9.5	8.0	6.4	-0.2	-1.0	-2.1	-0.2	-0.4	-0.8	-2.5	-0.3
Total	**-90.0**	**117.9**	**92.9**	**67.9**	**-6.4**	**-32.1**	**-64.2**	**-1.5**	**-3.0**	**-6.0**	**-101.3**	**-30.5**

Notes: S1 = scenario 1, S2 = scenario 2, S3 = scenario 3, Negative number = decrease of demand, Positive number = increase of demand.
Source: Author.

2.5. Reduction in CO_2 emission

Figure 2.12 shows the reduction in CO_2 emission, which can be attained by switching fuel from fossil fuel to hydrogen. In the phase 2 study, CO_2 emission will be reduced to 327 million tonnes-CO_2 in 2040. Compared to the phase 1 study, CO_2 emission will decrease by 68 million tonnes-CO_2 from scenario 1, 206 million tonnes-CO_2 from scenario 2, and 367 million tonnes-CO_2 from scenario 3. The main reason for reduced CO_2 emission is that coal-fired electricity generation was not included in calculating hydrogen demand potential in the phase 2 study.

Figure 2.12: CO_2 Emission Reduction in the EAS in 2040

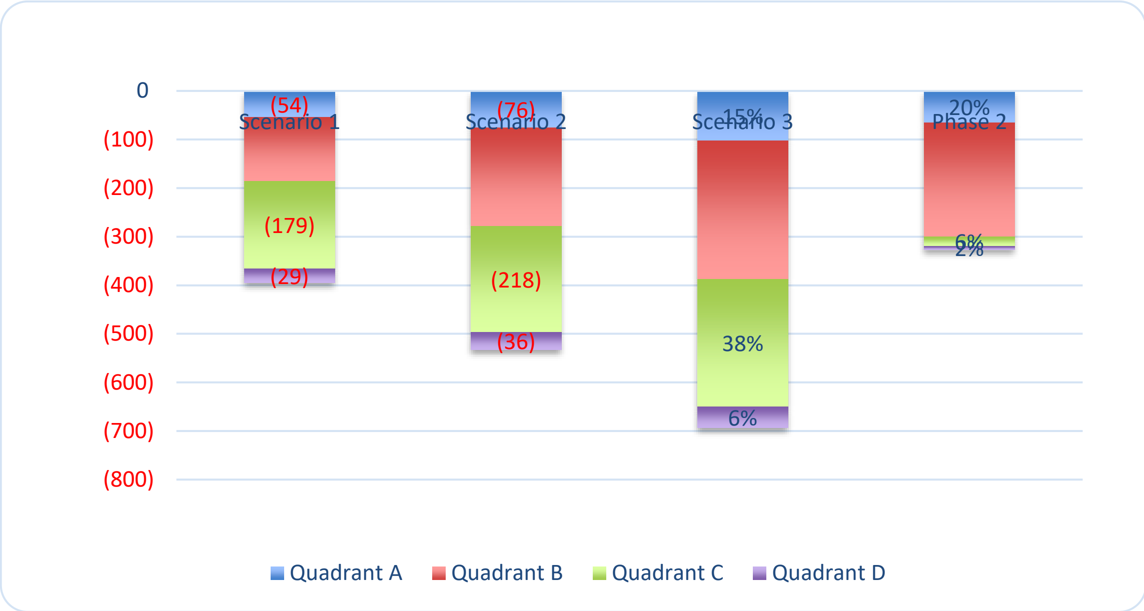


Source: Author.

Figure 2.13 shows the reduction in CO_2 emission in 2040 by quadrant.

Compared to the phase 1 study, quadrant A countries will increase CO_2 emission by 11 million tonnes-CO_2 from scenario 1 but will decrease 11 million tonnes-CO_2 from scenario 2 and 38 million tonnes-CO_2 from scenario 3. Quadrant B will increase 103 million tonnes-CO_2 from scenario 1 and 33 million tonnes-CO_2 from scenario 2 but will decrease 49 million tonnes-CO_2 from scenario 3. Quadrant C will decrease 160 million tonnes-CO_2 from scenario 1, 199 million tonnes-CO_2 from scenario 2, and 243 million tonnes-CO_2 from scenario 3. Quadrant D will decrease 22 million tonnes-CO_2 from scenario 1, 29 million tonnes-CO_2 from scenario 2, and 37 million tonnes-CO_2 from scenario 3.

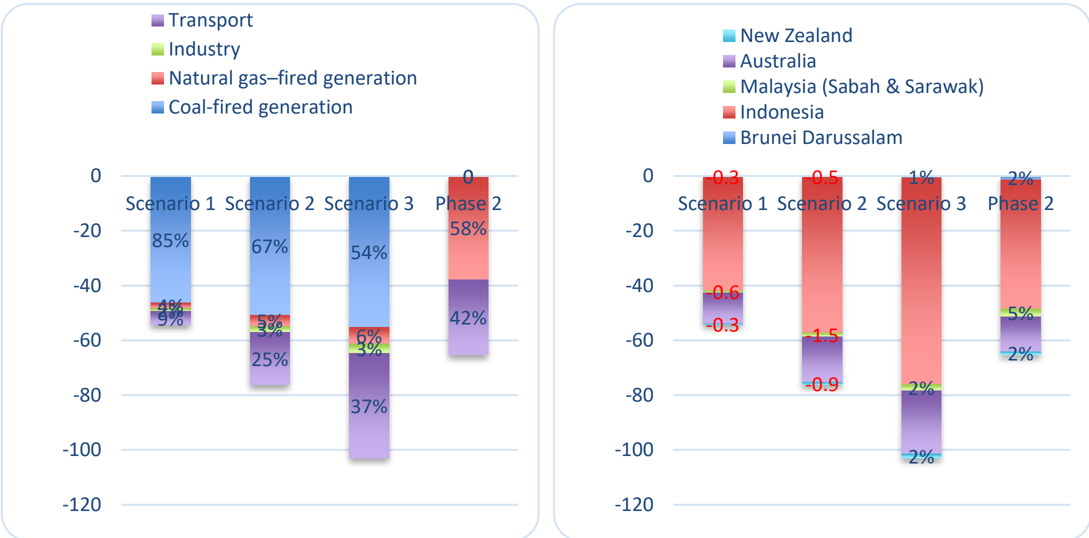
Figure 2.13: CO_2 Emission Reduction in 2040, by Quadrant

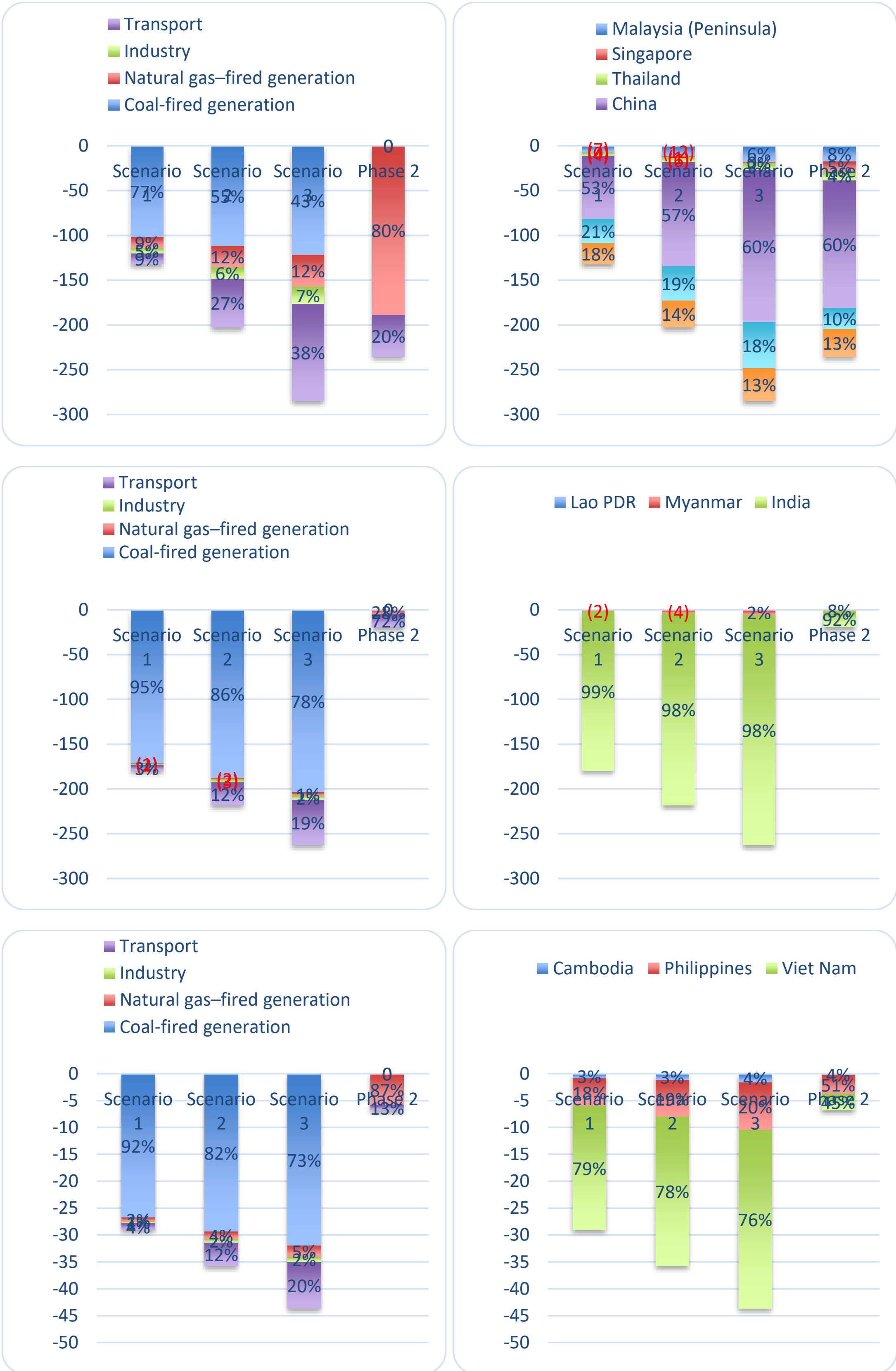


Source: Author.

Figure 2.14 shows the CO_2 emission reduction in 2040 by sector and by country.

Figure 2.14: CO_2 Emission Reduction in 2040, by Country and Sector





Source: Author.

3. Summary of Hydrogen Demand Potential

3.1. Hydrogen demand potential under the revised scenario

The scenarios estimating the hydrogen demand potential were revised from the phase 1 study by considering recent development of relevant technologies.

1) *Electricity generation sector*

   At present, 30% hydrogen mix natural gas combustion in combined cycle gas turbine (CCGT) is already commercially available. Further, commercial-scale pure hydrogen CCGT is being tested. Considering these developments, the phase 2 study excluded coal electricity generation, and adopted a more ambitious target, i.e. pure hydrogen CCGT to be commercialised after 2030, and fuel switch from natural gas electricity generation. With these changes, hydrogen demand potential was greater than in the phase 1 study.

2) *Industry sector*

   The industry sector was excluded in the phase 2 study.

3) *Transport sector*

   Competition amongst vehicle technologies is tougher. Development and deployment of battery electric vehicles are going forward, whilst FCVs are slow due to higher technology cost. Therefore, the study team decided to revise the expectation of future deployment of FCVs. Besides, the phase 2 study excluded diesel demand for bus and railway from the subject of estimation as their hydrogen potential is negligible.

Table 2.14 shows the estimated hydrogen demand potential under the new scenarios.

Table 2.14: EAS Hydrogen Demand Potential, by Sector (Summary)

Unit: Mtoe

Sector	Phase 1			Phase 2
	Scenario 1	Scenario 2	Scenario 3	
Coal-fired generation	14	29	43	–
Natural gas–fired generation	7	13	20	101
Industry	4	8	12	–
Transport	4	15	30	11
Total	29	65	105	113

Note: Due to rounding, the sum of the sectors does not match the total.
Source: Author.

3.2. Hydrogen demand potential by country group

In phase 2, analysis was made by applying different scenarios, unique fuel switch rate, for each country group. EAS countries are classified according to their hydrogen supply cost and income level.

Table 2.15: Classification of EAS Countries, Excluding the United States (Summary)

<table>
<tr><td></td><td></td><td colspan="2">Hydrogen Supply Cost</td></tr>
<tr><td></td><td></td><td>Cheap</td><td>Expensive</td></tr>
<tr><td rowspan="2">Income Level</td><td>High</td><td>A
Brunei Darussalam
Indonesia
Malaysia (Sabah and Sarawak)
Australia
New Zealand</td><td>B
Malaysia (Peninsula)
Singapore
Thailand
China
Japan
Republic of Korea</td></tr>
<tr><td>Low</td><td>C
Lao PDR
Myanmar
India</td><td>D
Cambodia
Philippines
Viet Nam</td></tr>
</table>

EAS = East Asia Summit.
Source: Author.

The estimated result is shown in Table 2.16. It shows a large hydrogen demand potential in quadrants A and B, whilst it is small in quadrants C and D. The results come from different perspectives for future power generation mix. The hydrogen demand potential is larger for countries where a large increase of natural gas electricity generation is expected, i.e. quadrants A and B countries. In contrast, countries where increase of natural gas electricity generation is small, those in quadrants C and D have a smaller hydrogen demand potential.

Table 2.16: EAS Hydrogen Demand Potential, by Quadrant (Summary)

Unit:Mtoe

Quadrant	Phase 1			Phase 2
	Scenario 1	Scenario 2	Scenario 3	
A	4	10	16	20
B	14	31	51	86
C	9	20	32	4
D	2	4	6	3
Total	**29**	**65**	**105**	**113**

EAS = East Asia Summit.
Source: Author.

3.3. Reduction in CO_2 emission

Fuel switch to hydrogen can anticipate a reduction in CO_2 emission. Table 2.17 shows the estimates. The estimated amount of CO_2 is smaller in the phase 2 study because fuel switch from carbon-intensive coal to hydrogen, which was included in the phase 1 study, was not included in phase 2.

Table 2.17: CO_2 Emission Reduction in the EAS, by Sector (Summary)

Unit: Million tonnes-CO_2

Sector	Phase 1			Phase 2
	Scenario 1	Scenario 2	Scenario 3	
Coal-fired generation	–346	–380	–413	–
Natural gas–fired generation	–16	–31	–47	–238
Industry	–10	–19	–29	–
Transport	–23	–102	–205	–88
Total	**–395**	**–533**	**–694**	**–327**

EAS = East Asia Summit.
Note: Due to rounding, the sum of sectors does not match the total.
Source: Author.

Likewise, in the estimation results of hydrogen demand potential, reduction in CO_2 emission is larger in quadrants A and B, and smaller in quadrants C and D.

Table 2.18: Comparison CO_2 Emission Reduction in the EAS (Summary)

Unit: Million tonnes–CO_2

Quadrant	Phase 1			Phase 2
	Scenario 1	Scenario 2	Scenario 3	
A	–54	–76	–103	–65
B	–132	–202	–284	–235
C	–179	–218	–263	–19
D	–29	–36	–44	–7
Total	–395	–533	–694	–327

EAS = East Asia Summit.
Note: Due to rounding, the sum of sectors does not match the total.
Source: Author.