CHAPTER 1

Main Report

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March 2021

This chapter should be cited as:
Han, P., S. Kimura, and C.L. Malik (2021), 'Main Report', in Han, P. and S. Kimura (eds.), *Energy Outlook and Energy Saving Potential in East Asia 2020*, Jakarta: ERIA, pp.1-32.

CHAPTER 1

Main Report

Han Phoumin, Shigeru Kimura and Cecilya Laksmiwati Malik

1. Introduction

From the outset of this study, members of the working group on the Energy Outlook for ASEAN and East Asia, who are experts from the countries of the East Asia Summit (EAS)[1] plus the United States (US) (EAS17), aimed to predict the growth of medium- to long-term energy demand and supply in 2017–2050. At the time of this writing, the world economy and energy demand has been hit hard by the coronavirus disease (COVID-19) pandemic, but energy demand is expected to bounce back strongly in 2021 as the economy recovers. The Economic Research Institute for ASEAN and East Asia (ERIA) will release the short-term energy outlook in a separate report.

In the medium to long term, population and economic growth in EAS17 are the key drivers of projected increasing primary energy supply, from 7,625 million tonnes of oil equivalent (Mtoe) in 2017 to 10,780 Mtoe under the business-as-usual scenario (BAU) and to 8,860 Mtoe under the alternative policy scenario (APS) by 2050, reflecting annual growth rates of 1.1% under BAU and 0.5% under APS in 2017–2050. Under BAU, the energy intensity in final energy consumption is expected to drop by 46% from 122 tonnes of oil equivalent (toe)/million US$ in 2017 to 64 toe/million US$ in 2050. In primary energy consumption, the emission intensity is expected to drop from 0.70 tonnes of carbon (t-C)/toe in 2017 to 0.65 t-C/toe in 2050 under BAU.

[1] EAS is a regional forum held annually by leaders of, originally, 16 countries: 10 ASEAN Member States (Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic [Lao PDR], Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam); Australia; China; India; Japan; the Republic of Korea; and New Zealand. EAS membership expanded to 18 countries, including Russia and the US, at the Sixth EAS in 2011. EAS17 refers to the 10 ASEAN+7 countries: the original EAS plus the US. Since its establishment, ASEAN has led the forum. EAS meetings are held after the annual ASEAN leaders' meetings and play an important role in the regional architecture of Asia and the Pacific.

The economy will become more energy-efficient but increasing energy demand will threaten the region's energy security. Potential energy saving is, therefore, key to reducing energy demand and carbon dioxide (CO2) emissions.

In 2007, leaders from the Association of Southeast Asian Nations (ASEAN) Member States, Australia, China, India, Japan, the Republic of Korea, and New Zealand adopted the Cebu Declaration on energy security (ASEAN Secretariat, 2007). They agreed to promote energy efficiency, new forms of renewable energy, and the clean use of coal. The leaders at the EAS Energy Minister Meeting (EMM) formed the EAS Energy Cooperation Task Force in response to the declaration, and Japan proposed to study energy saving and the potential of reducing CO2 emissions. The topic is an area of cooperation for which ERIA officially requested support through the EAS Energy Ministers Meeting (EAS–EMM).

This study shows the energy saving potential of BAU and APS. BAU was developed for each EAS country, outlining future sector and economy-wide energy consumption, assuming no significant changes to government policies. The APS was set to examine the potential impacts if additional energy-efficiency goals, action plans, or policies being or likely to be considered were developed. The difference between BAU and APS in final and primary energy supply represents potential energy saving. The difference in the two scenarios' CO2 emissions represents the potential to reduce them. The outlook's analysis covers EAS17. Underlying the EAS energy cooperation initiative is the Energy Research Institutes Network, of which the US is a member. Therefore, the outlook's analysis includes the US.

The study's findings shed light on the policy implications for decision-making to ensure that the region can enjoy economic growth and investment without compromising energy security and producing harmful CO2 emissions.

1.1. East Asia Summit

The EAS17 countries are diverse, with widely varying per capita incomes, standards of living, energy resources, climate, and energy consumption per capita. Some EAS17 countries are mature economies, most are developing. Several EAS17 countries had a per capita gross domestic product (GDP) of less than US$1,500 (in 2010 constant prices[2]) in 2017, whilst some mature economies had GDP per capita of more than US$53,000.

[2] All US dollars in this document are in constant 2010 values unless otherwise specified.

Mature economies have higher energy consumption per capita than developing ones. A large percentage of people in developing countries still meet their energy needs mainly with traditional biomass fuels.

These differences partly explain why energy efficiency and conservation (EEC) goals, action plans, and policies are assigned different priorities across countries. Developed economies might be keen to reduce energy consumption, whilst developing countries emphasise economic growth and improving standards of living. As developing economies grow, however, their energy consumption per capita is expected to grow as well.

Despite the differences amongst their countries, EAS17 leaders agreed that EAS 'could play a significant role in community building', which could be an important cornerstone of regional cooperation in years to come (Ministry of Foreign Affairs, 2005a).

1.2. Objective and Rationale

This study analyses the potential impacts of proposed additional energy-saving goals, action plans, and policies in EAS17 on energy consumption, by fuel, sector, and greenhouse gas (GHG) emissions. The study provides a platform for energy collaboration and capacity building amongst EAS17 countries on energy modelling and policy development.

The study supports the Cebu Declaration, the goals of which include the following:

(i) Improve the efficiency and environmental performance of fossil fuel use.

(ii) Reduce dependence on conventional fuels through intensified EEC programmes; increased share of hydropower; and expansion of renewable energy systems, biofuel production and/or utilisation, and, for interested parties, civilian nuclear power.

(iii) Mitigate GHG emissions through effective policies and measures to help abate global climate change.

The Government of Japan asked ERIA to conduct a study on energy saving and CO2 emission reduction potential in East Asia. Japan coordinates the energy-efficiency work stream under the Energy Cooperation Task Force. ERIA convened the working group to analyse energy saving potential. All EAS17 countries are represented in the working group.

2. Data and Methodology

2.1.Scenarios

Like the annual studies since 2007, the present study examines two scenarios: BAU, reflecting each country's current goals, action plans, and policies; and APS, including additional goals, action plans, and policies reported every year to the EAS–EMM. The latest updated policies were reported at the 13th EAS–EMM, 5 September 2019, Bangkok.

One might be tempted to call APS a 'maximum effort' but that would not be accurate. One reason is that goals, action plans, and policies for reducing energy consumption are still new in most countries. Many potential EEC policies and technological options have not been examined or incorporated in APS.

In 2014, APS assumptions were grouped into (i) more efficient final energy consumption (APS1), (ii) more efficient thermal power generation (APS2), (iii) higher consumption of new and renewable energy (NRE) and biofuels (APS3), and (iv) introduction or higher utilisation of nuclear energy (APS4). APS is the total of APS1 to APS4.

The energy models can estimate the individual impacts of the assumptions on primary energy supply and CO2 emissions. The combination of the assumptions constitutes the APS assumptions. The main report highlights only BAU and APS. However, each country report will analyse all APS.

Detailed assumptions for each APS are as follow:

(i) APS1 assumes the setting of reduction targets for sector final energy consumption, and the use of efficient technologies and implementation of energy-saving practices in the industry, transportation, residential and commercial, and even agriculture sectors in some countries. This scenario results in less primary energy and CO2 emissions in proportion to reduction in final energy consumption.

(ii) APS2 assumes the utilisation of more efficient thermal power plant technologies, resulting in lower primary energy supply and CO2 emissions in proportion to thermal power efficiency improvement. The most efficient coal and natural gas combined-cycle technologies are assumed to be utilised for new power plant construction.

(iii) APS3 assumes higher contributions of NRE to electricity generation and utilisation of liquid biofuels in transportation. The scenario results in lower CO_2 emissions as NRE is carbon-neutral or will not emit additional CO_2. However, the primary energy supply might not decrease because NRE, like biomass and geothermal energy, is assumed to be less efficient than fossil fuel–fired generation in converting electricity into primary energy equivalent.

(iv) APS4 assumes the introduction of nuclear energy or a higher contribution of nuclear energy in countries already using it. The scenario produces less CO_2 emissions as nuclear energy emits minimal CO_2. However, as thermal efficiency in converting nuclear energy output into primary energy is assumed to be only 33%, the primary energy supply is not expected to be lower than under BAU.

All EAS17 countries are developing and implementing EEC goals, action plans, and policies, but progress has varied widely. Some countries are advanced in their efforts, while others are just getting started. A few countries have significant energy-saving goals, action plans, and policies built into BAU, while others have only started to quantify their goals. However, significant potential does exist in these countries at the sector and economy levels.

Every country still has a great deal to learn about what works and what does not. It is worthwhile updating this study periodically, as the quality and scope of national goals, action plans, and policies are likely to improve considerably, allowing for collaboration across countries.

2.2.Data

For consistency, the historical energy data used in this analysis come from the energy balances of EAS17 countries' energy statistics. Cambodia, Lao People's Democratic Republic (Lao PDR), and Myanmar use their national energy statistics produced with ERIA's support, and the seven other ASEAN countries use the Asia-Pacific Economic Cooperation energy database, which includes national energy data submitted by them. The seven other EAS countries use energy balance tables produced by the International Energy Agency (IEA) (IEA, 2020). The socio-economic data for all EAS17 countries were obtained from the World Bank's online World Databank – World Development Indicators and Global Development Finance.

Other data, such as those relating to transportation, buildings, and industrial production indices, were provided by the working group members from each EAS17 country where such data are available. Where official data are not available, estimates were obtained from other sources or developed by the Institute of Energy Economics, Japan (IEEJ), especially for international energy prices such as the crude oil price.

2.3. Methodology

In 2007, IEEJ's World Energy Outlook Model was used to prepare Asia/World Energy Outlook (IEEJ, 2014). Since 2008, all ASEAN Member States have used their own energy models. The seven other EAS17 countries still depend on the IEEJ model but provide their own key assumptions on population and GDP growth; electric generation fuel mixes; and EEC goals, action plans, and policies.

ASEAN countries. The energy models of ASEAN countries were developed using the Long-range Energy Alternative Planning System (LEAP) software, which is used to project energy balance tables based on final energy consumption and energy input and/or output in the transformation sector. Final energy consumption is forecast using energy demand equations by energy and sector and future macroeconomic assumptions. For this study, all ASEAN Member States used the LEAP model.

Other countries. IEEJ produced energy outlooks for other countries using its model, which has explanatory variables based on exogenously specified GDP growth rates. The IEEJ model projects prices for natural gas and coal based on exogenously specified oil price assumptions. Demand equations are econometrically calculated in another module using historical data, and future parameters are projected using the explanatory variables. An econometric approach means that future demand and supply will be heavily influenced by historical trends. However, energy supply and new technologies are treated exogenously. For electricity generation, the working group members specified assumptions about the future electricity generation mix in their countries by energy source. These assumptions were used to determine the future electricity generation mix.

3. Assumptions of the Study

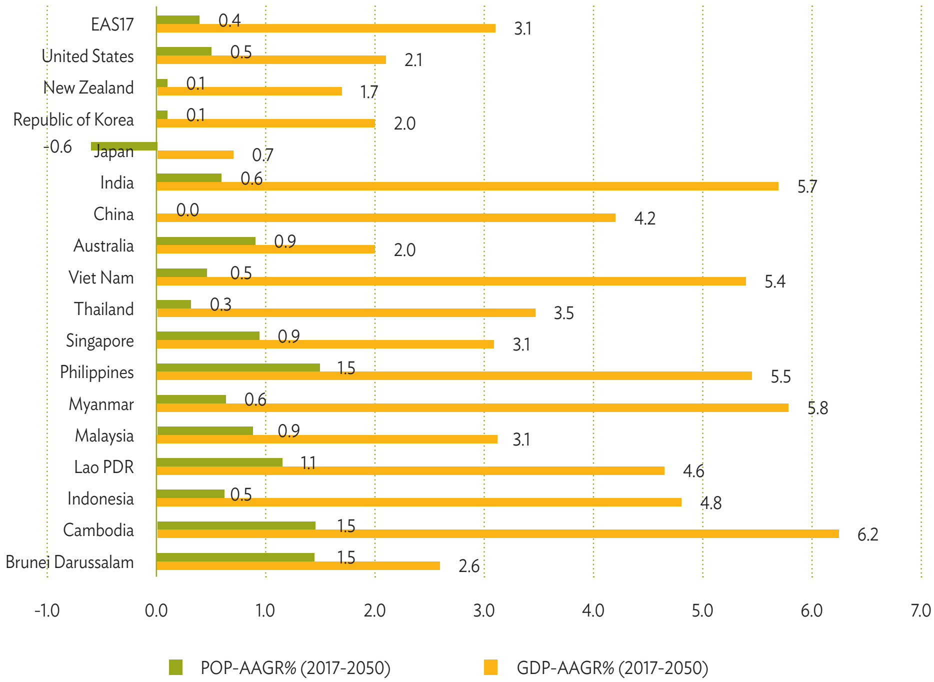
Growth in energy consumption and GHG emissions is driven by socio-economic factors. In EAS17, these factors – including growing population, sustained economic growth, increasing vehicle ownership, and greater access to electricity – will push up energy demand. Together they create a huge growth 'headwind' that works against efforts to limit energy consumption. Understanding the nature and size of the 'headwind' is critical for any analysis of energy demand. However, increased consumption of energy services is fundamental for achieving a range of socio-economic development goals.

This section discusses the assumptions about key socio-economic indicators and energy policies for EAS17 countries until 2050.

3.1. Size of Population, Gross Domestic Product, and Its Growth Rate in EAS17

In the study's models, changes in population until 2050 are set exogenously. No difference in population between BAU and APS is assumed. EAS17 countries, except China, submitted assumed changes in population based on projections from the United Nations.

Figure 1.1. Average Annual Growth Rate of Gross Domestic Product and Population in EAS17 Countries



In 2017, the total EAS17 population was about 3.89 billion. It is projected to increase at an average annual rate of about 0.4% to about 4.43 billion in 2050.

Brunei Darussalam, Cambodia, Lao PDR, and the Philippines are generally assumed to have the fastest average annual population growth rate, at 1.1%–1.5% in 2017–2050 (Figure 1-1). Indonesia, Malaysia, Singapore, Thailand, Viet Nam, Australia, India, and the US are expected to have a moderate average annual population growth rate, at 0.5%–0.9%. The Republic of Korea and New Zealand are expected to have an extremely slow average population growth rate, at just 0.1%. Japan's population is assumed to decline slowly as it continues to age, resulting in an average annual population growth rate of –0.6%.

Long-term economic growth rates are assumed to be high in developing countries, with the highest in Cambodia, India, Myanmar, the Philippines, Viet Nam, and Lao PDR (Figure 1-1). Economic growth in other developing countries is assumed to be rapid. Brunei Darussalam is expected to have a moderate average annual GDP annual growth rate of 2.6% in 2017–2050. The United States, Japan, Republic of Korea, New Zealand, and Australia are expected to have a moderate annual GDP growth rate. Rapid growth in China, India, Indonesia, and the United States is likely to be especially significant for energy demand in these large economies.

In 2017, total GDP in EAS17 was about $42 trillion in 2010 US dollar constant prices and accounted for about 52% of global GDP. The region's GDP is assumed to grow at an average annual rate of about 3.1% in 2017–2050, implying that, by 2050, the region's total GDP will reach about US$114.6 trillion in 2010 US dollar constant prices. China is projected to be the largest economy, with real GDP of about $39.7 trillion in 2010 US dollar constant prices, followed by the US with about $33.9 trillion by 2050. India and Japan are projected to be the next-largest economies, with projected GDPs of about $16.3 trillion and $7.7 trillion, respectively, at 2010 US dollar constant prices by 2050 (Table 1-1).

Average real GDP (2010 US dollar constant prices) per capita in EAS17 is assumed to increase from $10,776.70 in 2017 to $25,765.00 in 2050. However, there are, and will continue to be, significant differences in GDP per capita amongst EAS17 countries. In 2017, per capita GDP (2010 US dollar constant prices) ranged from $1,234.60 in Cambodia to more than $48,000.00 in Japan, the US, Singapore, and Australia. In 2050, per capita GDP is assumed to range from $5,496.20 in Cambodia to more than $113,000.00 in Singapore.

Table 1.1. Gross Domestic Product (in constant 2010 US dollar prices) and Population in EAS17 Countries (2017–2050)

	GDP (billion, 2010 US dollar constant prices)		Population (million)		Per Capita GDP	
	2017	2050	2017	2050	2017	2050
Brunei Darussalam	13.5	29.0	0.4	0.7	33,750.0	41,428.6
Cambodia	20.0	144.0	16.2	26.2	1,234.6	5,496.2
Indonesia	1,090.5	5,131.2	264.6	324.3	4,121.3	15,822.4
Lao PDR	12.6	80.6	7.1	11.4	1,774.6	7,070.2
Malaysia	364.6	992.5	31.1	41.4	11,723.5	23,973.4
Myanmar	79.5	510.9	53.4	65.8	1,488.8	7,764.4
Philippines	303.3	1,463.9	105.1	164.4	2,885.8	8,904.5
Singapore	318.4	871.1	5.6	7.7	56,857.1	113,129.9
Thailand	424.2	1,304.6	69.2	76.8	6,130.1	16,987.0
Viet Nam	175.3	995.7	93.7	108.9	1,870.9	9,143.3
Australia	1,432.7	2,776.2	24.6	32.8	58,239.8	84,640.2
China	10,161.1	39,687.5	1,386.4	1,403.2	7,329.1	28,283.6
India	2,650.8	16,319.9	1,339.1	1,639.8	1,979.5	9,952.4
Japan	6,157.7	7,786.5	126.8	105.2	48,562.3	74,016.2
Republic of Korea	1,345.9	2,299.9	51.5	50.1	26,134.0	45,906.2
New Zealand	181.1	314.6	4.8	6.1	37,729.2	51,573.8
United Sates	17,348.6	33,922.1	325.1	384.1	53,363.9	88,315.8
EAS17	42,079.8	114,630.2	3,904.7	4,448.9	10,776.7	25,766.0

GDP = gross domestic product, Lao PDR = Lao People's Democratic Republic, US = United States.

Source: Authors.

3.2. Thermal Efficiency of Power Generation

The thermal efficiency of electricity generation reflects the amount of fuel required to generate a unit of electricity and was an exogenous assumption used in the study. Base year 2017 thermal efficiencies by fuel type (coal, gas, and oil) were derived from fossil fuel input and fuel output as electricity production. Thermal efficiencies by fuel (coal, gas, and oil) were projected by Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam, and growth rates in thermal efficiency were derived from the projections. For the other countries, assumptions about potential changes in thermal efficiency were based on IEEJ's Asia/World Energy Outlook 2017.

Thermal efficiencies may differ significantly amongst countries due to differences in technological availability, age of technology, cost of technology, temperatures, and cost and availability of fuel inputs. Thermal efficiency in EAS17 countries is expected to improve considerably under BAU as more advanced generation technologies, such as natural gas combined-cycle and supercritical coal-fired power plants, become available. In many countries, additional improvements are assumed under APS (Figures 1-2 and 1-3).

Figure 1.2. Average EAS17 Thermal Efficiency under Business as Usual

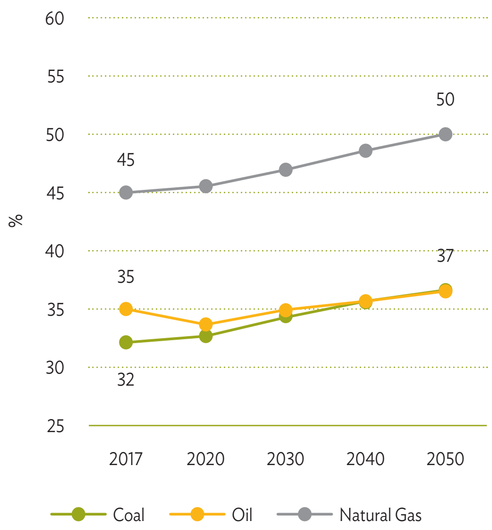
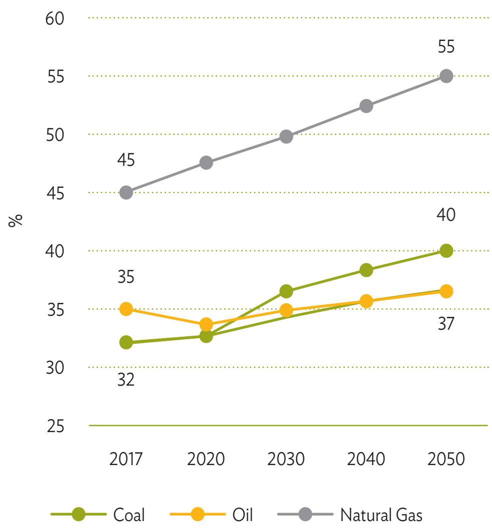


Figure 1.3. Average EAS17 Thermal Efficiency under Alternative Policy Scenario



EAS = East Asia Summit.
Source: Authors.

3.3. Imported Price Assumption for Oil, Coal, and Natural Gas

Table 1-2 depicts the oil price assumptions used in the modelling as adopted by IEEJ from the world energy model price data of IEA (2019). Under the reference scenario, the crude oil price was US$71/blue barrel (bbl) in 2018. It will rise to US$120/bbl by 2030 and to US$236/bbl in 2050 due to combined factors such as robust demand growth in non–Organisation for Economic Co-operation and Development (OECD) countries, emerging geopolitical risks and financial factors, and oil supply constraints reflecting rising depletion rates for oil fields, amongst others.

Table 1.2. Imported Price Assumption for Real Oil, Natural Gas, and Coal (2018 US dollar constant prices)

Year	Crude Oil ($/bbl)	Coal ($/ton)	Natural Gas ($/MBtu)		
			US	Europe	Asia
2015	52	80	3	7	10
2016	44	74	2	5	7
2017	54	99	3	6	8
2018	71	118	3	8	10
2020	80	95	3	8	9
2030	95	100	4	8	9
2040	115	104	4	8	10
2050	125	105	5	9	10

Note: 2018 US dollar constant prices are used for the energy outlook for Australia, China, India, Japan, the Republic of Korea, and New Zealand. 2018 nominal prices are used for ASEAN countries. Crude oil price assumptions start from 2018.
bbl= blue barrel, MBtu = 1,000 British thermal units, toe = ton of oil equivalent.
Source: IEEJ (2018).

Table 1.3. Assumptions of Energy-Saving Targets under the Alternative Policy Scenario in EAS17

Country	Assumptions
Australia	Energy-efficiency target of 40% improvement in 2015–2030
Brunei Darussalam	Reduction of total energy consumption by 63% under BAU by 2035; 10% share of renewables in the power mix by 2035
Cambodia	Total energy saving of 27% under BAU by 2030; specific fuel efficiency target by 2050 (10% for coal, oil, gas, biomass; 20% for electricity)
China	CO_2 emissions will peak by 2030. China aims to achieve carbon neutrality before 2060.
India	Emission intensity (CO_2 produced for every dollar of GDP) reduced by 33%–35% by 2030 from 2005 levels. Share of non–fossil fuels increases to 40% in the power mix by 2030 from 2005 levels.
Indonesia	Committed to reduce GHG emissions by 29% unconditionally under BAU by 2030
Japan	Reduce GHG emissions by 26% from 2013 levels by 2030.
Republic of Korea	Reduce GHG emissions by 37% under BAU by 2030.
Lao People's Democratic Republic	Increase the share of small-scale renewable energy to 30% in the power mix by 2030. Biodiesel: 20% blend from 1% to 5% in 2010. Biofuels make up 10% of road transport fuels by <year>.
Malaysia	16% electricity saving by 2050 in industry, commercial, and residential sectors. 16% oil saving in final consumption by 2050. Replace 5% of diesel in road transport with biodiesel.
Myanmar	Target saving by 2050: transport and residential sectors by 20%; industry, commercial, and other sectors by 10%. Replace 8% of transport diesel with biodiesel.
New Zealand	Reduce GHG emissions by 30% from 2005 levels by 2030.
Philippines	20% saving on oil and electricity by 2050. Displace 20% of diesel and gasoline with biofuels by 2025.
Thailand	Energy-efficiency targets by 2050: transport 70%, residential 10%, commercial 40%, and industry 20% reduction in final energy demand. Biofuels to displace 12.2% of transport energy demand.
United States	Withdrew from the Paris Agreement. It is hoped that the US will re-join it. Its past commitment was to reduce GHG emissions by 26%–28% from 2005 levels by 2025.
Viet Nam	Committed to reduce GHG emissions by 8% unconditionally under BAU by 2030. Energy consumption to be reduced by 20% under BAU in all sectors by 2030.

Source: Kimura and Han (2019).

3.4. Energy Saving Goals and Other Policy Assumptions

The working group members included information on policy assumptions and targets under BAU and APS. Some EAS17 countries have clear targets for energy saving or emission reduction. Table 1-3 summarises the policy assumptions.

4. Energy Outlook for the East Asia Summit Region

4.1.Business-as-Usual Scenario

4.1.1.Final Energy Consumption

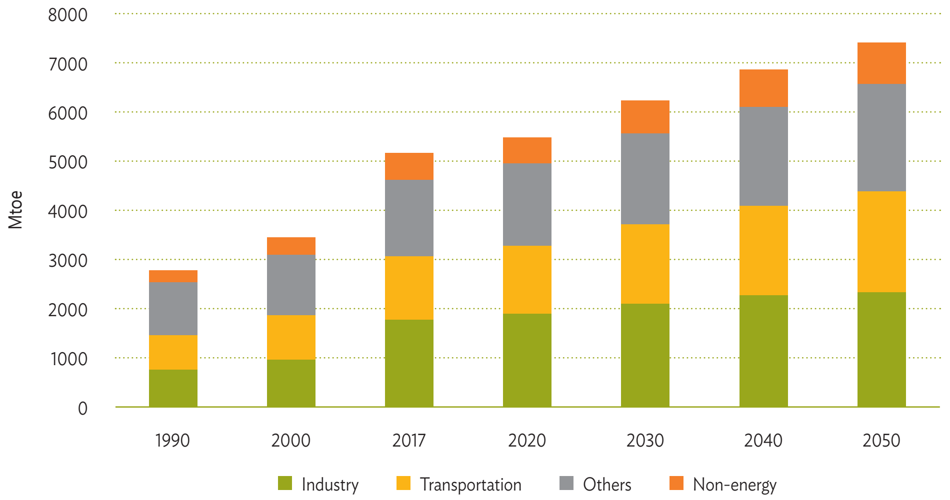
In 2017–2050, total final energy consumption[3] in EAS17 is projected to grow at an average annual rate of 1.1%, reflecting the assumed 3.1% annual GDP and 0.4% population growth. Final energy consumption is projected to increase from 5,159 Mtoe in 2017 to 7,416 Mtoe in 2050. Transportation energy demand is projected to grow moderately by about 1.4% per year, and its energy consumption share is projected to be 27.7% by 2050. Industry's annual growth rate in 2017–2050 is projected at about 0.9% per year, but its energy consumption share is projected to be the largest at about 31.7% by 2050.

Commercial and residential demand will grow by 1.0% per year, higher than that of industry. However, commercial and residential energy consumption share is projected to be 29.3%, the second largest after industry. Figure 1-4 shows final energy consumption by sector under BAU in EAS17 from 1990 to 2050, and Figure 1-6 shows details of sector shares in final energy consumption.

Figures 1-6 and 1-7 show final energy consumption and shares by fuel type in EAS17 under BAU from 1990 to 2050. By energy source, electricity and natural gas demand under BAU are projected to show the fastest growth, increasing by 1.9% and 1.5% per year, respectively, from 2017 to 2050, but their shares are just 28.4% for electricity and 14.0% for natural gas. Although oil will retain the largest share at 39.9% of total final energy consumption, it is projected to grow by only 1.2% per year in 2017–2050, reaching 2,960 Mtoe in 2050. Generally, the oil share slightly increases from 38.3% in 2017 to 39.9% in 2050. Coal demand

[3] Refers to energy in the form in which it is consumed, i.e. including electricity but not including the fuels and/or energy sources used to generate electricity.

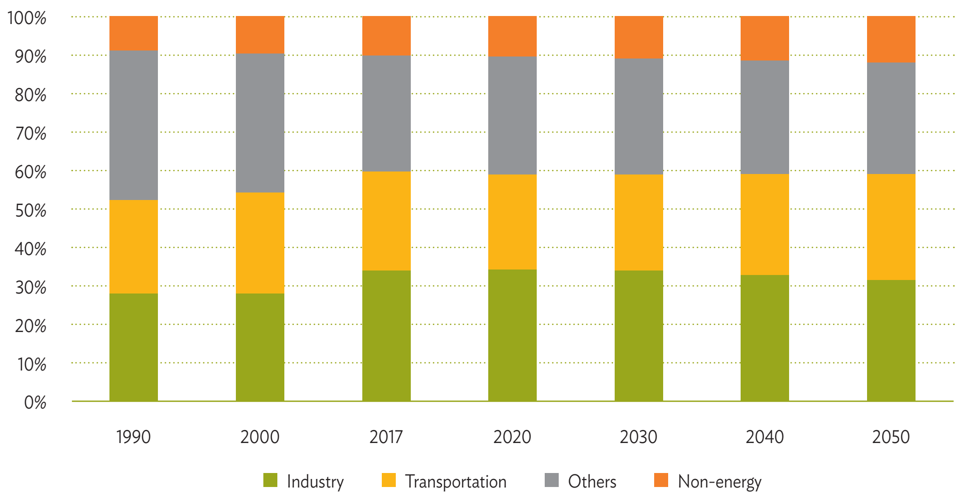
Figure 1.4. Final Energy Consumption by Sector, Business as Usual (1990–2050)



BAU = business as usual, Mtoe = million tons of oil equivalent.

Source: Authors.

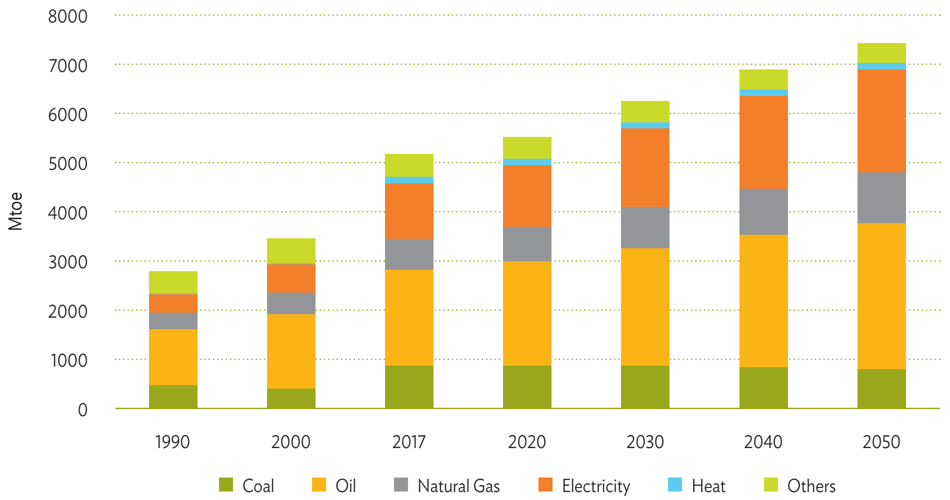
Figure 1.5. Final Energy Consumption Share by Sector (1990–2050)



Source: Authors.

will grow at –0.2% per year on average from 2017 to 2050, reaching 800.5 Mtoe in 2050. The share of other fuels such as biomass will decline from 9.2% in 2017 to 5.2% in 2050. The slow growth is due to the gradual shift from non-commercial biomass to conventional fuels such as liquefied petroleum gas and electricity in the residential sector.

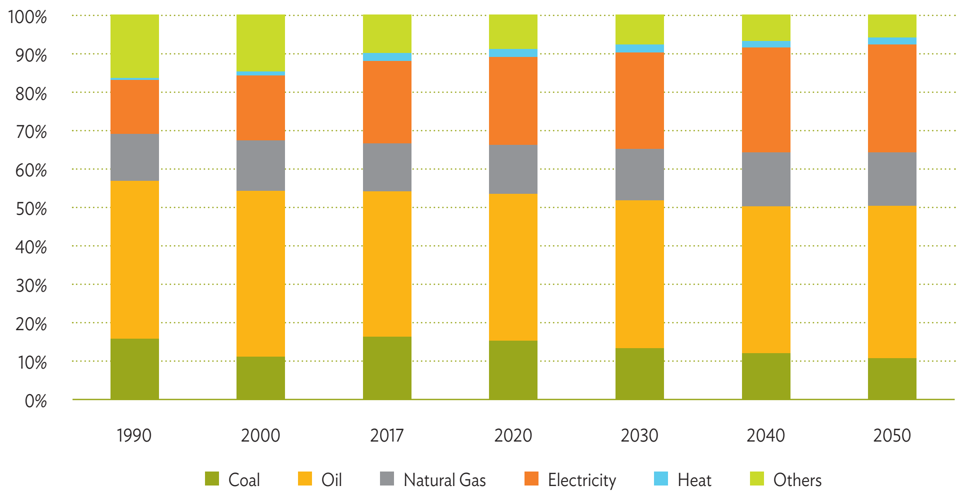
Figure 1.6. Final Energy Consumption by Fuel (1990–2050)



Mtoe = million tons of oil equivalent.

Source: Authors.

Figure 1.7. Final Energy Consumption Share by Fuel (1990–2050)



Source: Authors.

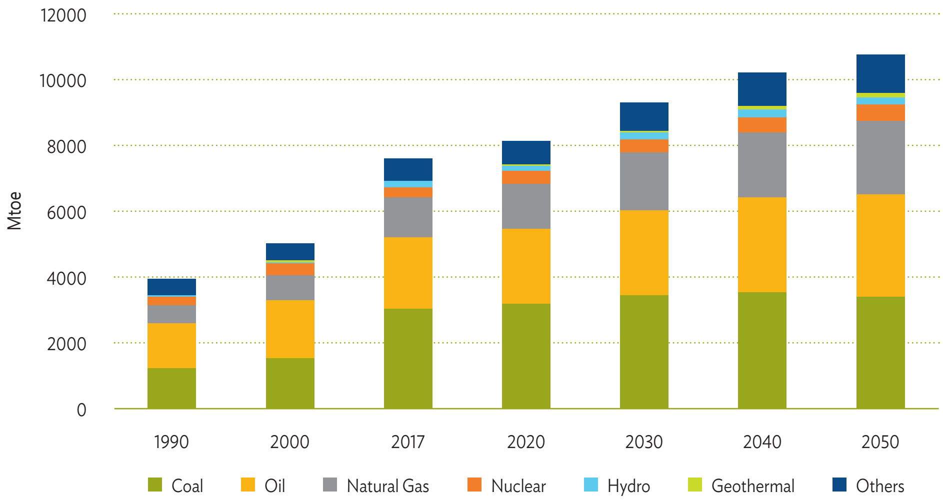
4.1.2. Primary Energy Supply (Business as Usual)

Figure 1-8 shows primary energy supply in EAS17 from 1990 to 2050.[4] It is projected to grow slowly at 1.1% per year in 2017–2050, the same growth rate of final energy consumption. EAS17 primary energy supply is projected to increase from 7,625 Mtoe in 2015 to 10,780

[4] Refers to energy in its raw form, before any transformation.

Mtoe in 2050. Coal will still comprise the largest share of primary energy supply, but its growth is expected to be slower, increasing at 0.3% per year in 2017–2050.

Figure 1.8. Primary Energy Supply in EAS17 (1990–2050)



EAS = East Asia Summit, Mtoe = million tons of oil equivalent.

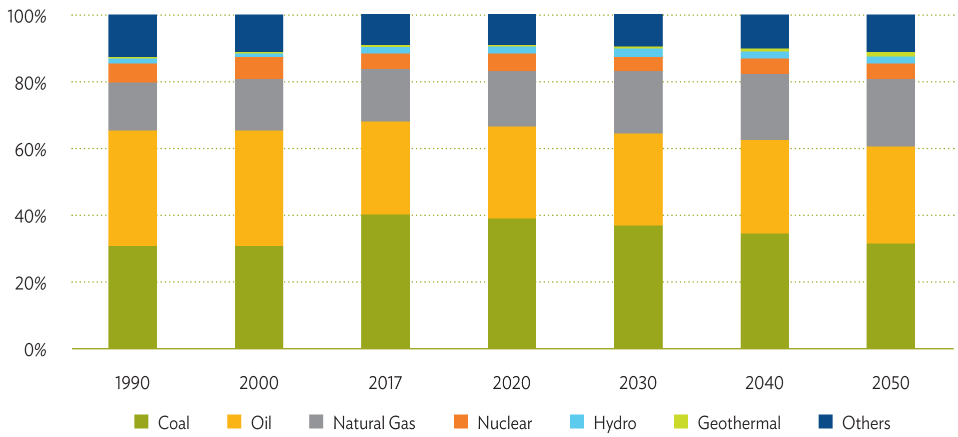
Source: Authors.

Consequently, the share of coal in total primary energy supply (TPES) is forecast to decline from 40.2% in 2017 to 31.7% in 2050.

Amongst fossil sources of energy, natural gas is projected to see moderate growth in 2017–2050, increasing at an annual average rate of 1.9%. Its share in the total will consequently increase from 15.7% (equivalent to 1,199 Mtoe) in 2017 to 20.6% (2,217 Mtoe) in 2050. Nuclear and hydropower energy are projected to increase slowly at 1.1% per year on average in 2017-2050; the share of nuclear energy will stay at 4.5% and that of hydropower at 2.2%. It is assumed that nuclear power generation in Japan and the expansion of nuclear power generation capacity in China and India will resume. Geothermal energy is projected to grow at 3.3% per year in 2017–2050, but its share is projected to be small: about 1.3% by 2050, increasing from 0.6% in 2017.

Amongst the energy sources, 'others' – which are made up of solar, wind, and solid and liquid biofuels – will see a growth rate of 1.8% in 2017–2050, with their share increasing from 8.6% in 2017 to 10.8% in 2050. Most remarkably, wind and solar energy will see the largest average annual growth rate: 5.2% in 2017–2050, with their share in the primary energy supply increasing from 1.4% in 2017 to 5.4% in 2050. Figure 1-9 shows the share of each energy source in the total primary energy mix in 1990–2050.

Figure 1.9. Share of Primary Energy Mix by Source (1990–2050)

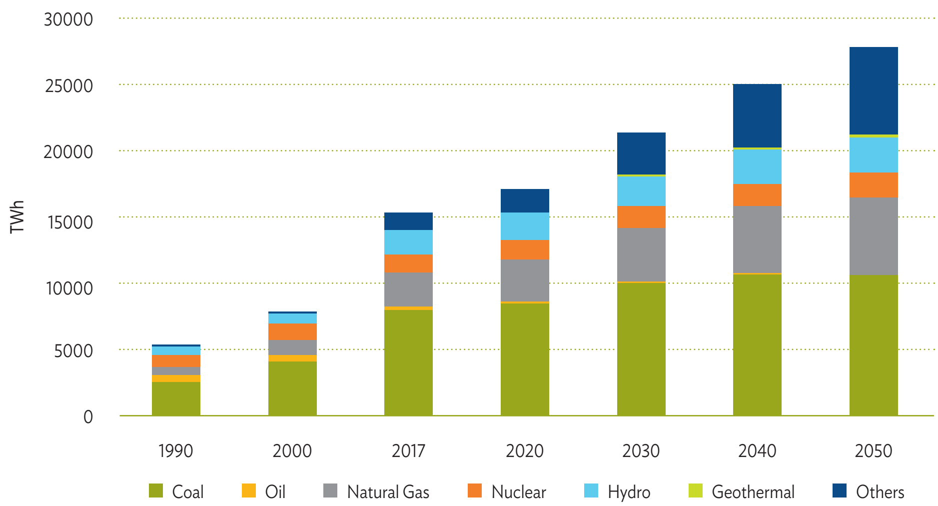


Source: Authors.

4.1.3. Power Generation in EAS17

Figure 1-10 shows power generation output in EAS17. Total power generation is projected to grow at 1.8% per year on average from 2017 (equivalent to 15,365 terawatt-hours [TWh]) to 2050 (27,812 TWh). However, the growth rate in 1990–2017 was 3.9%, more than twice that projected in 2017–2050.

Figure 1.10. Energy Mix of Power Generation in EAS17 (1990–2050)

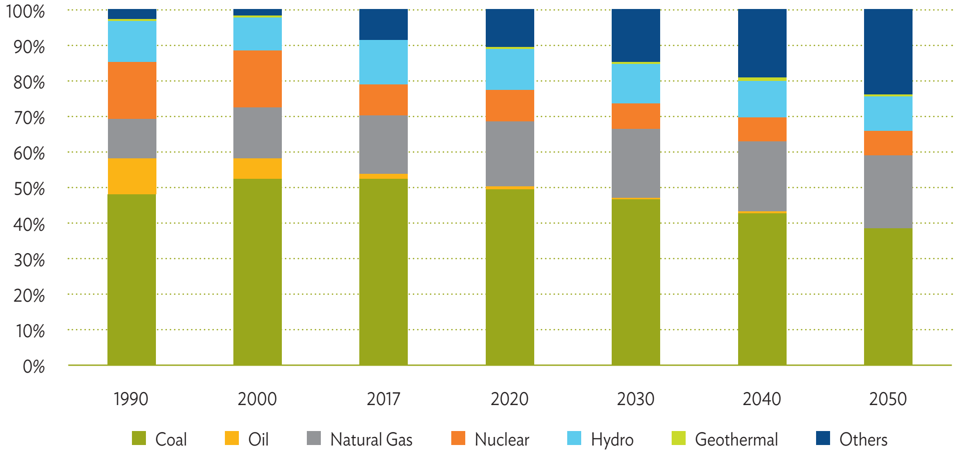


EAS = East Asia Summit, TWh = terawatt-hour.

Source: Authors.

Figure 1-11 shows the share of each energy source in electricity generation from 1990 to 2050. The share of coal-fired generation is projected to continue to be the largest at 38.4% in 2050, a large drop from 52.7% in 2017. The share of natural gas is projected to increase from 16.8% in 2017 to 20.8% in 2050. The share of nuclear power (8.5% in 2017) is forecast to decrease to 6.7% in 2050. The share of geothermal energy was 0.3% in 2017 and is projected to increase to 0.6% in 2050. Other sources (wind, solar, biomass, etc.) will record the highest average annual growth rate at 5.2% in 2017–2050. The share of combined wind, solar, and biomass energy in the power mix is expected to be 23.6% in 2050, a large increase from 8.0% in 2017. The share of oil will drop from 1.2% in 2017 to 0.1% in 2050. Oil is expected to grow at an average annual rate of –4.4% in 2017–2050 due to its higher fuel cost. The share of hydropower is projected to decrease, from 12.4% in 2017 to 9.7% in 2050. The average annual growth rate of hydropower is expected to be slow, at 1.1% in 2017–2050.

Figure 1.11. Share of Power Generation Mix in EAS17 (1990–2050)



Source: Authors.

4.1.4. Energy Indicators in EAS17 (Business as Usual and Alternative Policy Scenario)

Figures 1-12 and 1-13 show the energy indicators from 2017 to 2050 for BAU and APS, respectively. The data have been normalised to 100 for the base year 2017. For BAU, primary energy intensity (toe/million US$ in 2010 prices) in EAS17 is projected to decline by 48.1%[5] in 2050 from 2017 levels. Under APS, energy intensity is expected to drop further by 57.3% from 2017 levels.

[5] This can be calculated by taking the normalised number in 2050 and minus 100, which is the normalised number to 100 in base year 2017. In this case, the reduction from the base year is 51.9%–100.0%.

The improvement in primary energy intensity is reflected in improved carbon intensity (t-C/ million US$ in 2010 prices). Under BAU, carbon intensity is expected to drop by 52.2% in 2050 from 2017 levels. Under APS, carbon intensity is expected to drop by 70.4% in 2050 from 2017 levels. The difference in BAU and APS carbon intensity in 2017–2050 is the result of the fundamental shift from fossil fuel to renewables.

Energy demand per capita under BAU is projected to increase by 24.3% in 2050 compared with 2017 levels. Under APS, energy demand per capita is expected to increase slightly by 2.1% in 2050 from 2017 levels. The difference between BAU and APS energy demand per capita in 2017–2050 explains the fundamental change in terms of energy efficiency from BAU to APS. The increase in energy per capita in 2050 compared with 2017 levels can be attributed to projected continuing economic growth, which will bring about a more energy-intensive lifestyle as people are able to purchase vehicles, household appliances, and other energy-consuming devices due to increases in disposable income.

Figure 1.12. Energy Indicators in EAS17 (Business as Usual)

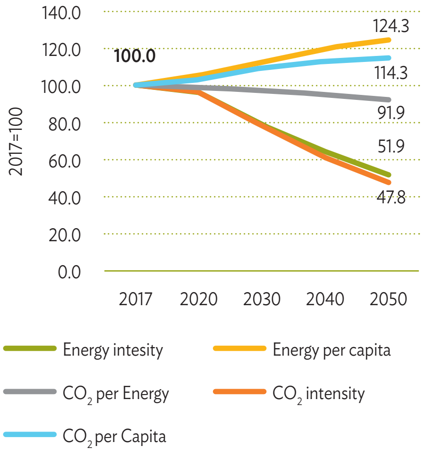
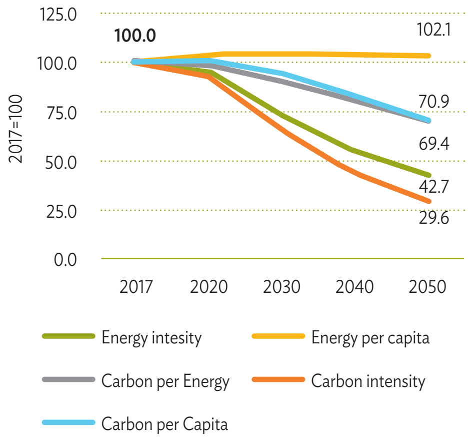


Figure 1.13. Energy Indicators in EAS17 (Alternative Policy Scenario)



Note: Data in 2017 is normalised to 100.

CO_2 = carbon dioxide, EAS = East Asia Summit.

Source: Authors.

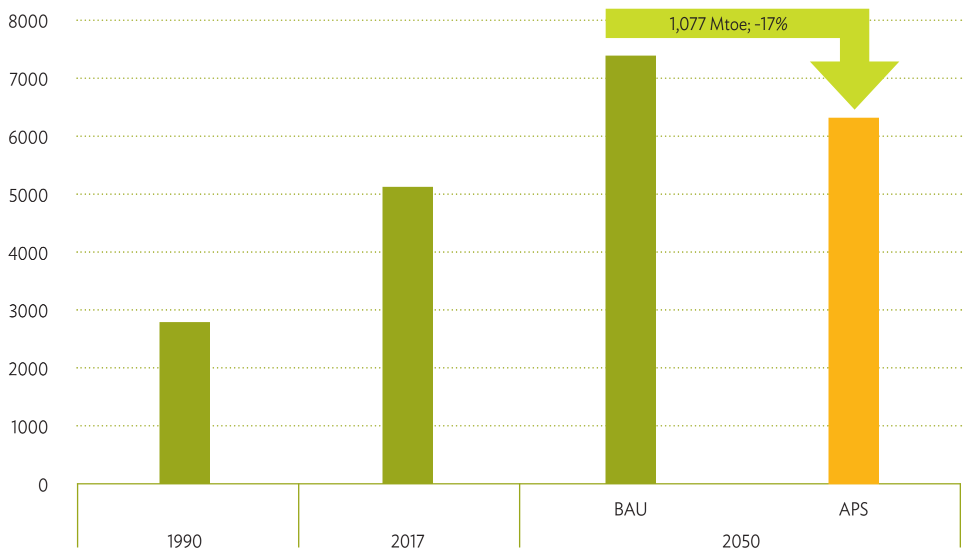
4.2.Comparison of Business as Usual and Alternative Policy Scenario

4.2.1.Total Final Energy Consumption

Under APS, final energy consumption is projected to rise from 5,160 Mtoe in 2017 to 6,338 Mtoe in 2050. In 2050, the difference between BAU and APS is 1,077 Mtoe, with APS 17% lower than BAU, because of energy-efficiency plans and programmes for supply and demand sides to be implemented by EAS17 countries. Figure 1-14 shows final energy consumption in 1990–2050 under BAU and APS.

Potential energy saving in total final energy consumption in EAS17 (1,077 Mtoe) in 2050 is more than double ASEAN's total final energy consumption in 2017 (480 Mtoe). Energy saving in EAS17 is expected largely from the transportation, industry, commercial, and residential sectors.

Figure 1.14. Total Final Energy Consumption, Business as Usual and Alternative Policy Scenario

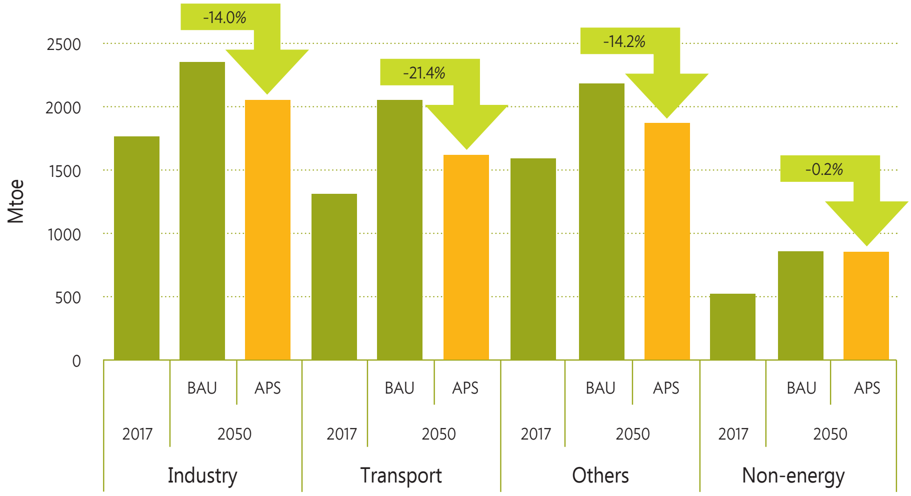


APS = alternative policy scenario, BAU = business as usual, Mtoe =million tons of oil equivalent.

Source: Authors.

Figure 1-15 shows the composition of final energy consumption by sector under BAU and APS. Final energy consumption in most sectors is significantly more reduced under APS than under BAU. The reduction is largest in transportation (21.4%), followed by 'others' (14.2%) and industry (14.0%). Non-energy demand will drop slightly by 0.2% from BAU.

Figure 1.15. Final Energy Consumption by Sector, Business as Usual and Alternative Policy Scenario



APS = alternative policy scenario, BAU = business as usual, Mtoe = million tons of oil equivalent.

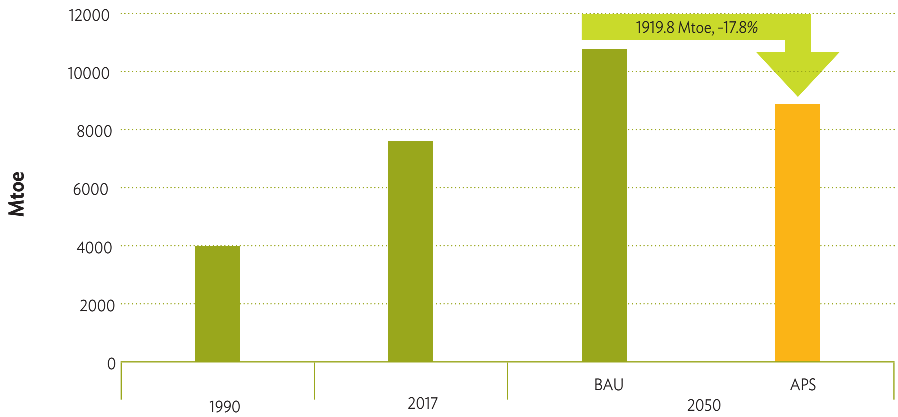
Source: Authors.

4.2.2. Primary Energy Supply

Figure 1-16 shows TPES of 10,779.6 Mtoe under BAU and 8,859.7 Mtoe under APS in 2050. Total saving potential is the difference between BAU and APS in 2050. Total saving potential in TPES is expected to be 1,919.8 Mtoe, representing a 17.8% reduction from BAU to APS.

The energy-saving potential results from improvements in the transformation sector, particularly power generation, and final energy consumption sectors such transportation, industry, and the residential and commercial sector, where efficiencies are expected.

Figure 1.16. Total Primary Energy Supply, Business as Usual and Alternative Policy Scenario

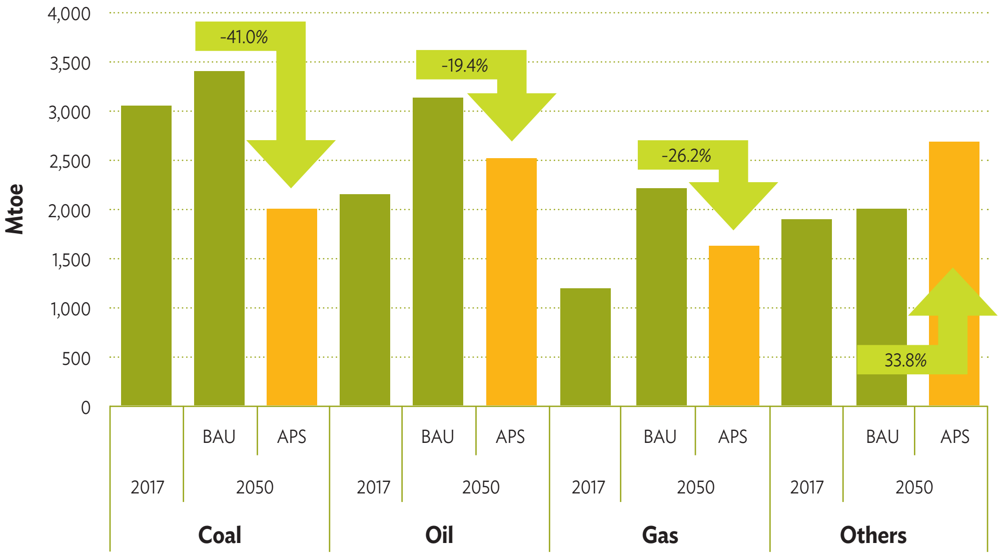


APS = alternative policy scenario, BAU = business as usual, Mtoe = million tons of oil equivalent.

Source: Authors.

Figure 1-17 shows primary energy supply by fuel source. Under APS, growth in primary energy supply for fossil fuels is lower than under BAU. The growth rate in primary energy supply under APS is projected at 0.5% per year on average in 2017–2050, which is lower than under BAU, projected at 1.1%. In absolute terms, the largest reduction will be in coal demand, by 1,401 Mtoe or 41% from 3,414.7 Mtoe under BAU to 2,013.7 Mtoe under APS. Potential savings for other fuels are projected at 608.9 Mtoe for oil (equivalent to a 19.4% reduction under BAU) and 580.6 Mtoe for gas (26.2% reduction under BAU). Due to increased renewable energy in the primary supply, renewable energy supply, including solar wind and biomass, is projected to increase by 33.8% from BAU to an APS of aggressively including more renewables into the supply mix.

Figure 1.17. Primary Energy Supply by Source, Business as Usual and Alternative Policy Scenario



APS = alternative policy scenario, BAU = business as usual, Mtoe = million tons of oil equivalent.

Source: Authors.

4.3. Carbon Dioxide Emissions from Energy Consumption

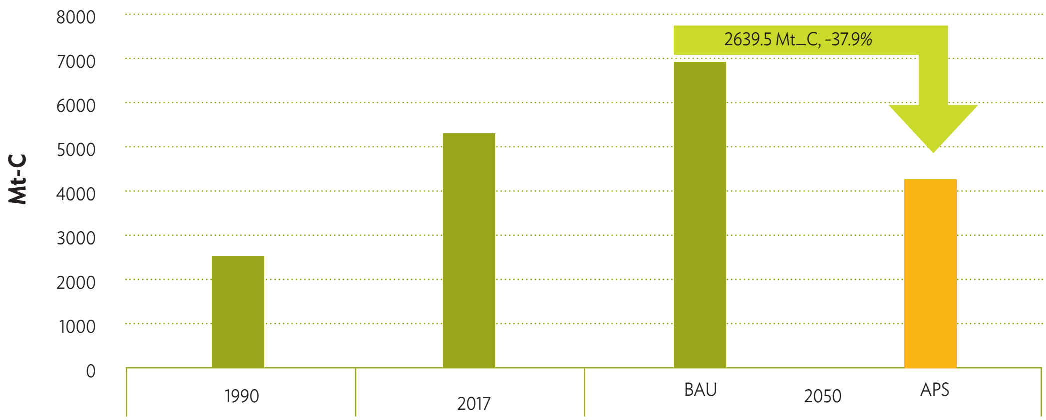
4.3.1. Carbon Dioxide Emissions

Figure 1-18 shows CO2 emissions under BAU and APS. CO2 emissions from energy consumption under BAU are projected to increase from 5,352.4 million tonnes of carbon (Mt-C) in 2017 to 6,957.3 Mt-C in 2050, implying an average annual growth rate of 0.8% in 2017–2050. The growth rate of emissions is lower than that of TPES of 1.1% per year. The reason is that the share of renewables in the energy mix is increasing. Under APS, CO2 emissions are projected at 4,317.8 Mt-C in 2050, 37.9% lower than under BAU.

At the 21st Conference of the Parties (COP21) in Paris, December 2015, 195 countries adopted the first universal binding global climate deal. The agreement sets out a global action plan to put the world on track to avoid dangerous climate change by limiting global warming to well below 2 degrees Celsius (°C) compared with pre-industrial levels. The Paris Agreement could bridge today's policies and climate-neutrality before the end of the century.

The CO2 emission reductions under APS in 2050 are significant but emission levels are still higher than in 2017. However, CO2 emissions due to energy demand under APS in 2050 will still be higher than 1990 levels. Scientific evidence suggests that these reductions will not be adequate to prevent severe climate change impacts. Analysis by the Intergovernmental Panel on Climate Change suggests that to keep the increase in global mean temperature to not more than 2oC compared with pre-industrial levels, global CO2 emissions would need to fall by 45% from 2010 levels by 2030. Under the Paris Agreement, the parties will 'pursue efforts' to limit the temperature increase to 1.5°C, which will require zero emissions in 2030–2050 (IPCCC, 2015). However, EAS, especially the ASEAN Member States, will need to balance abating climate change with energy access and affordability. Thus, the clean use of fossil fuel through innovative technologies such as clean coal technology and carbon capture utilisation and storage (CCUS) will a play central role in carbon sink around the globe.

Figure 1.18. Total Carbon Dioxide Emissions, Business as Usual and Alternative Policy Scenario



APS = alternative policy scenario, BAU = business as usual, CO_2 = carbon dioxide, Mt-C = million tonnes of carbon equivalent.

Source: Authors.

4.4. Necessary Energy Infrastructure Investment Cost

4.4.1. Power Generation Investment

Based on the energy outlook results, BAU, and APS, the working group estimated the necessary investment in the power sector, especially for coal, gas, nuclear, hydro, geothermal, solar photovoltaic, wind, and biomass power generation plants. The working group drew from several sources of information to obtain the current capital cost of each power plant but did not forecast capital cost due to its uncertainty. For all EAS17 countries taken together, the amount of investment to meet electricity demand would be US$3.92 trillion under BAU and US$5.93 trillion under APS. The investment cost considers the reduction of upfront cost of each technology due to the fast drop of unit cost of each technology, especially renewables. Figures 1-19 and 1-20 show the share of investment cost by power generation type under BAU and APS. The increment of electricity demand from 2017 to 2050 under BAU will be 12,447 TWh and under APS 9,844 TWh. The shift to a higher share of renewables in the power mix under APS will add the required 4,680 gigawatts (GW) of the incremental capacity of combined solar, wind, and biomass under APS in 2017–2050. Under BAU, the incremental capacity of combined wind, solar, and biomass energy is expected to be 2,584 GW, which is lower than under APS. Necessary investment in power generation will be higher under APS than under BAU, and the share of power generation sources will be different under BAU and APS.

Figure 1.19. Investment Share by Power Source (EAS17, Business as Usual)

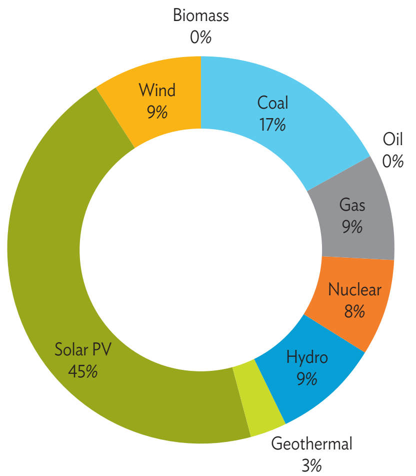
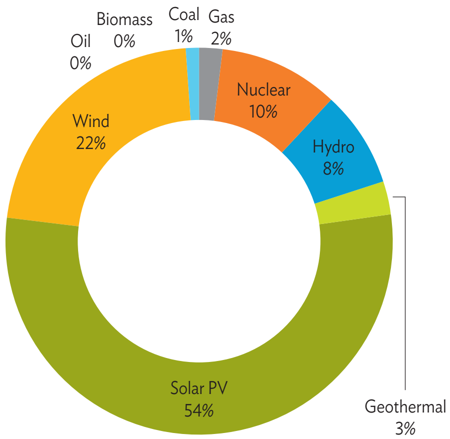


Figure 1.20. Investment Share by Power Source (EAS17, Alternative Policy Scenario)



BAU = business as usual, APS = alternative policy scenario, EAS = East Asia Summit, PV = photovoltaic.

Source: Authors.

Figures 1-21 and 1-22 show the share of investment cost of power generation in ASEAN under BAU and APS. ASEAN will require investment in power generation of about US$540.2 billion under BAU and about US$502.9 billion under APS in 2017–2050. The lower investment cost of power generation under APS than under BAU is due to energy efficiency and saving that reduce power demand under APS. However, the investment cost in the power mix under APS will be greater for renewables. Under BAU, investment in coal and gas power will dominate in ASEAN. However, investment under APS will be in clean energy such as hydro, geothermal, wind, solar photovoltaic, and possibly nuclear energy (Figures 1-22 and 1-23). ASEAN will seek a more balanced energy mix for power generation to increase energy security and mitigate CO2 emissions.

Figure 1.21. Investment Share by Power Source (ASEAN, Business as Usual)

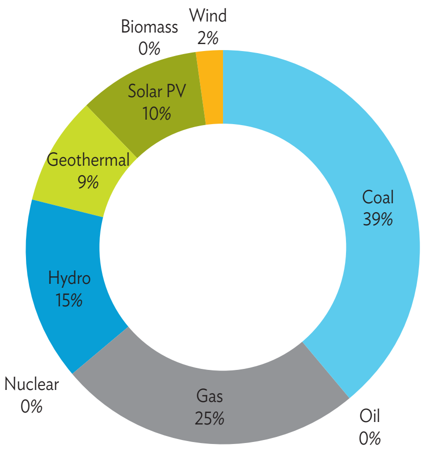
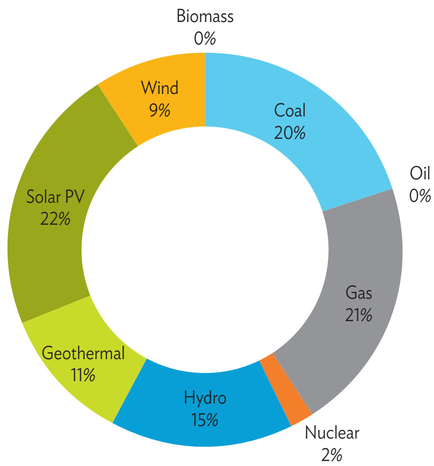


Figure 1.22. Investment Share by Power Source (ASEAN, Alternative Policy Scenario)



BAU = business as usual, APS = alternative policy scenario, EAS = East Asia Summit, PV = photovoltaic.

Source: Authors.

4.4.2 Total Energy Infrastructure Investment

Total energy infrastructure investment in 2017–2050 includes investment in power generation, refineries, and liquefied natural gas (LNG)–receiving terminals. Total energy infrastructure investment in EAS17 is estimated at US$4.49 trillion under BAU and US$6.01 trillion under APS in 2017–2050, in which the share of power generation will dominate (Figures 1-23 and 1-24). The investment cost of refineries in EAS17 is estimated at US$410 billion under BAU. This study predicted that under APS, there will be no additional investment cost for refineries due to energy saving and conservation effects. The investment cost of LNG-receiving terminals in EAS17 is estimated at US$164 billion under BAU and US$77 billion under APS. Under APS, investment is less in refineries and LNG-receiving terminals due to the promotion of energy efficiency. However, these investment costs will be much lower than power generation costs. In EAS17, the share of combined investment cost in refineries and LNG-receiving terminals to total energy infrastructure investment will be 12.7% under BAU and 1.3% under APS. These results indicate energy transition from fossil fuel to more advanced energy technologies such as renewable energy.

Figure 1.23. Total Energy Infrastructure Investment (EAS17, Business as Usual and Alternative Policy Scenario)

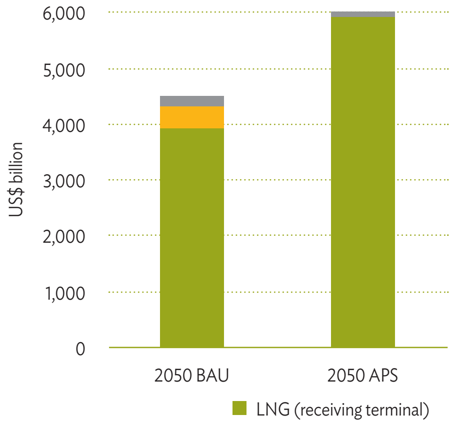
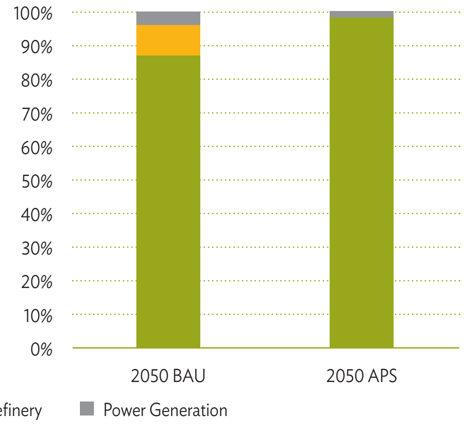


Figure 1.24. Share of Energy Infrastructure Investment (EAS17, Business as Usual and Alternative Policy Scenario)



APS = alternative policy scenario, BAU = business as usual, LNG = liquefied natural gas.

Source: Authors.

In ASEAN, investments in refineries and LNG-receiving terminals are estimated at US$322 billion and US$52 billion, respectively, under BAU (Figure 1-25). Investments in ASEAN under APS are reduced to US$233 billion for refineries and US$34 billion for LNG-receiving terminals. The shares of combined investment cost of refineries and LNG-receiving terminals to total energy infrastructure investment are estimated at 40% under BAU and 35% under APS (Figure 1-26). ASEAN will still need fossil fuel. Total investment cost for power generation, refineries, and LNG-receiving terminals under APS will be lower than under BAU, which indicates that EEC in the final energy consumption sector and natural gas power plants will be crucial.

Figure 1.25. Total Energy Infrastructure Investment (ASEAN, Business as Usual and Alternative Policy Scenario)

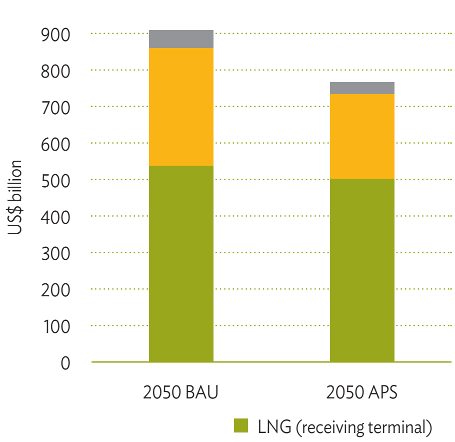
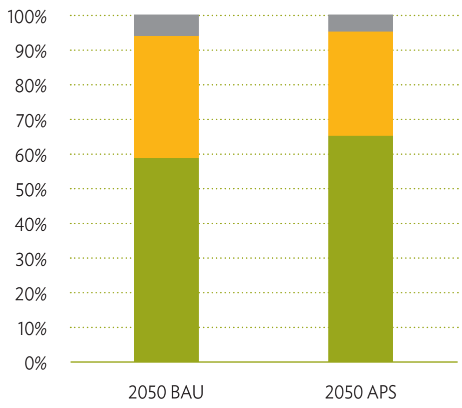


Figure 1.26. Share of Energy Infrastructure Investment (ASEAN, Business as Usual and Alternative Policy Scenario)



APS = alternative policy scenario, BAU = business as usual, LNG = liquefied natural gas.

Source: Authors.

5. Conclusions and Recommendations

Sustained economic growth in all EAS17 countries is key to their people's well-being. Although the world economy has been impacted by the COVID-19 pandemic throughout 2020, economic growth is expected to be positive starting in 2021. The post-pandemic era will see increasing energy consumption. Decades of sustained economic growth, especially in ASEAN and India, have increased per capita incomes, significantly reducing poverty and raising living standards for hundreds of millions.

With economic growth will come increasing access to and demand for electricity and rising levels of vehicle ownership. Continued reliance on fossil fuels to meet increasing energy demand might be associated with increasing GHG emissions and climate change challenges unless low emission technologies are used. Even if fossil fuel resources are enough, oil will likely be imported from other regions and no assurance can be given that it will be secure or affordable. EAS17 will need resilient energy infrastructure.

5.1. Key Findings

Based on projected changes in socio-economic factors, energy consumption, and CO2 emissions under BAU and APS, the working group members identified several key findings:

(i) In 2050, fossil fuels (coal, oil, and gas) will retain the dominant share in primary energy supply, final energy consumption, and power generation mix in EAS17 under BAU (80%) and APS (70%). In final energy consumption, the share of fossil fuels will be 65% under BAU and 62% under APS. In power generation, the share of fossil fuels is projected at 60% under BAU and 35% under APS.

(ii) Total final energy consumption in 2050 will increase by almost 44% under BAU and by 23% under APS compared with demand in 2017. The increase reflects actual average annual growth rate of 1.1% under BAU and 0.6% under APS per year in 2017–2050. Transportation energy demand is projected to grow moderately at about 1.4% per year under BAU and 0.6% under APS, and its energy consumption share is projected at 27.7% under BAU and 25.5% under APS by 2050. The annual growth rate of industry in 2017–2050 is slow at 0.9% per year under BAU and 0.4% under APS, but its energy consumption share is projected to be the largest at about 31.7% under BAU and 31.9% under APS by 2050. Commercial and residential ('others') demand will grow at 1.0% per year under BAU and 0.5% under APS, slower than transportation demand. However, commercial and residential energy consumption share is projected at 29.3% under BAU and 29.4% under APS, the second-largest share after industry.

(iii) Total EAS17 power generation is projected to grow at an average annual rate of 1.8% under BAU and 1.5% under APS in 2017–2050, reflecting an 81% and 64% increase from 2017 under BAU and APS, respectively, by 2050. The share of coal-fired generation is projected to continue to be the largest at about 38.4% under BAU and 19.5% under APS by 2050, a large drop from 52.7% in 2015. The share of natural gas is projected to increase from 16.8% in 2015 to 20.8% under BAU and 15% under APS by 2050. The nuclear share (8.5% in 2017) is forecast to decrease to 6.7% under BAU and to increase to 9.3% under APS by 2050. Geothermal share (0.3% in 2017) will increase to 0.6% under BAU and to 1.0% under APS by 2050. The share of 'others', including wind, solar, and biomass sources, is projected to increase from 8.0% in 2017 to 23.6% under BAU and 43.2% under APS by 2050. The hydro share is projected to decrease from 12.4% in 2017 to 9.7% under BAU and 11.9% under APS by 2050. The share of oil in power generation was negligible in 2017 and will continue to be so under BAU and APS.

(iv) Total EAS17 primary energy supply is projected to increase from 7,624 Mtoe in

2017 to 10,780 Mtoe under BAU and 8,860 Mtoe under APS by 2050. Coal will still comprise the largest share of primary energy supply but its growth is expected to be slow, at an average annual rate of 0.3% under BAU and at –1.3% under APS in 2017–2050. Consequently, the share of coal in TPES is forecast to decline from 40.2% in 2017 to 31.7% under BAU and 22.7% under APS by 2050. Amongst fossil sources of energy, natural gas is projected to see a moderate annual average growth rate of 1.9% under BAU and 0.9% under APS in 2017–2050. The share of natural gas in the total will increase from 15.7% in 2017 to 20.6% under BAU and 18.5% under APS by 2050. The share of nuclear energy was 4.5% in 2017 and is projected to remain unchanged under BAU and increase to 6.9% under APS by 2050. The reason is the assumed resumption of nuclear power generation in Japan and the expansion of nuclear power generation capacity in China and India. Geothermal energy is projected to grow fastest at 3.3% under BAU and 4.0% under APS in 2017–2050. However, its share was small at 0.6% in 2017 and is projected at 1.3% under BAU and 1.9% under APS by 2050.

(v) The continuing reliance on fossil fuels to meet increasing energy demand will be associated with significant increases in CO2 emissions. CO2 emissions from energy consumption under BAU are projected to increase from 5,352 Mt-C in 2017 to 6,957 Mt-C under BAU and decrease to 4,318 Mt-C under APS by 2050, implying an average annual growth rate of 0.8% under BAU and –0.6% under APS in 2017–2050. Under APS, CO2 emissions are projected to be 38% lower than under BAU. Since the emission reductions under APS are significant, CO2 emissions from energy demand under APS in 2050 will still be below 2017 levels but about 1.5 times higher than in 1990. EEC and renewable energy targets in EAS17 provide great hope that energy demand and CO2 emissions will be reduced. The results of this analysis indicate that, by 2050, the implementation of currently proposed energy-efficiency and renewable energy goals, action plans, and policies across the region could lead to the following reductions:

(a) Large energy saving in primary energy supply is expected to be 1,920 Mtoe in 2050, representing 17.8% potential reduction from BAU to APS in 2050.

(b) Primary energy intensity will be reduced by 48.1% under BAU and by 57.3% under APS from 2017 levels. [6]

[6] 2017 is the base year of energy intensity and normalised to 100.

(c) Under BAU, carbon intensity is expected to drop by 52.2% by 2050 from 2017 levels. Under APS, carbon intensity is expected to drop by 70.4% by 2050 from 2017 levels. The differences in carbon intensity between BAU and APS in 2017–2050 are the result of the shift towards more energy-efficient and renewable energy technologies and less energy-intensive economic activities in EAS17.

(d) Energy demand per capita under BAU is projected to increase by 24.3% in 2050 compared with 2017 levels. Under APS, energy demand per capita is expected to increase slightly by 2.1% in 2050 from 2017 levels. The differences in energy demand per capita between BAU and APS in 2017–2050 are the result of the fundamental change in terms of energy efficiency from BAU to APS.

(e) The necessary investment cost of combined power generation, refineries, and LNG-receiving terminals in EAS17 is estimated at US$4.49 trillion under BAU and US$6.01 trillion under APS in 2017–2050, with power generation dominating the total share of investment. For all EAS17 countries taken together, the amount of investment needed to meet electricity demand is US$3.92 trillion under BAU and US$5.93 trillion under APS. The investment cost of refineries in EAS17 is estimated at US$410 billion under BAU. This study predicted that under APS, there will be no additional investment cost for refineries due to energy saving and conservation effects. The investment cost of LNG-receiving terminals in EAS17 is estimated at US$164 billion under BAU and US$77 billion under APS.

5.2. Policy Implications

The working group identified several policy implications, aggregated into five categories:

enhance action plans in specific sectors, prepare energy-efficiency policies, shift from fossil to non-fossil energy, rationalise energy-pricing mechanisms, and ensure that energy consumption statistics are accurate. Policies will differ between countries based on their circumstances, policy objectives, and market structures. Not all working group members agreed on all the recommendations:

(1) Energy-efficiency action plans in final consumption sectors. The industry, transportation, and commercial sectors will be major sources of energy saving. Several

EEC action plans will need to be introduced, implemented, and accelerated. The policies are listed by area and/or sector:

- Energy efficiency in industry will need to be applied. Energy service companies will play a crucial role in energy saving. Some ASEAN countries will need to accelerate the introduction of energy service companies, and national energy policies will need to require industries that consume large amounts of energy to have energy managers and energy auditing.

- The road transportation sector will need to consider measures to improve the fuel economy and shift to low-emission fuels such as biofuel and compressed natural gas.

- For commercial and residential energy efficiency, passive and active design policies are important. Passive design measures include setting up and enforcing building codes and rewards for green buildings, supporting energy service companies regulated by governments, and exploring and establishing a practical green building business model to fit various contexts and situations. Active design measures to improve energy efficiency include applying standard and labelling systems, using demand management systems for households and factories, developing energy managers and energy service companies, and improving thermal efficiency in power generation by constructing or replacing facilities with new and more efficient technologies.

(2) Renewable energy policies. Low-carbon fuels should be increased by enlarging the share of renewables and clean fuel such as hydrogen and nuclear energy in the energy mix. Several policies and actions need to be considered:

- Set targets and shares of renewables such as wind, solar, and biomass in the energy mix. Supportive renewable energy policies such as feed-in-tariff, renewable portfolio standard, and net metering are suggested according to the situation and the evolution of the cost perspective of these renewables and clean technologies. Supportive international financing schemes such as the Clean Development Mechanism[7] and the Joint Credit Mechanism[8] for renewables and energy efficiency are needed.

[7] Allows emission-reduction projects in developing countries to earn certified emission reduction credits, each equivalent to 1 ton of CO2.

[8] A project-based bilateral offset crediting mechanism initiated by the Government of Japan to facilitate the diffusion of low-carbon technologies.

- The intermittent nature of renewable energy sources poses significant challenges in integrating renewable-energy generation with existing electricity grids. Thus, electricity storage technologies, combined with solar and wind power, and on-site hydrogen production for curtailed renewable electricity will be important. The combination cost is still high, however, and will need the right policy and framework to drive it down.

(3) Technology development policies. Environmental technologies will need to be considered to curb increasing CO2 emissions:

- The development of CCUS technology will be important in controlling GHGs. Continued research and development, including the CCUS value chain, will be important to ensure the economic viability of deploying CCUS technology.

- Hydrogen could be extracted from fossil fuels, such as low-ranked coal and natural gas, through electrolysis using renewable energy. But hydrogen is still more expensive than other fuels. Hydrogen fuel development is promising and could be commercialised. Continued research and development in fuel cells and hydrogen power generation will be important for clean fuel use.

- Technological cooperation and technology diffusion, including the hydrogen value chain, will need to be accelerated in ASEAN.

(4) Energy supply security policies. Several measures are identified based on the OECD practice of increasing oil stockpiling requirements (IEA, 2020):

- Promote regional energy connectivity such as the trans-ASEAN gas pipeline using a virtual pipeline (LNG).

- Diversify sources of imports.

- Strengthen energy infrastructure, including the construction of LNG-receiving terminals and re-gasification plants.

- ASEAN might need to consider public and private strategic reserves or stockpiling requirements in the near future.

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