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Energy Reality and Emissions in ASEAN: Energy Modelling Scenarios and Policy Implications

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Abstract: *The Association of Southeast Asian Nations (ASEAN) faces tremendous challenges regarding the future energy landscape and how the energy transition will embrace a new architecture – including sound policies and technologies to ensure energy access together with affordability, energy security, and energy sustainability. Given the high share of fossil fuels in ASEAN's current energy mix (oil, coal, and natural gas comprise almost 80%), the clean use of fossil fuels through the deployment of clean technologies is indispensable for decarbonising ASEAN's emissions. The future energy landscape of ASEAN will rely on today's actions, policies, and investments to change the fossil fuel-based energy system towards a cleaner energy system, but any decisions and energy policy measures to be rolled out during the energy transition need to be weighed against potentially higher energy costs, affordability issues, and energy security risks. This paper employs energy modelling scenarios to seek plausible policy options for ASEAN to achieve more emissions reductions as well as energy savings, and to assess the extent to which the composition of the energy mix will be changed under various energy policy scenarios. The results imply policy recommendations for accelerating the share of renewables, adopting clean technologies and the clean use of fossil fuels, and investing in climate-resilient energy quality infrastructure.*

Keywords: Business as usual (BAU), alternative policy scenarios (APSs), energy transition, renewables, clean technologies, fossil fuels, resiliency

JEL Classification: O21, Q20, Q30, Q40, Q50

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1. Introduction

At the time of writing, the world has been struggling with the coronavirus disease (COVID-19) pandemic, which has damaged the world economy – including the Association of Southeast Asian Nations (ASEAN). The global economy is being pushed into a recession by the COVID-19 pandemic due to preventive and containment measures such as country lockdowns, travel restrictions, and slow or even negative growth in many sectors such as tourism, retail, and industry. The magnitude of the economic impacts is hard to predict as it depends on the success of the pandemic containment efforts around the world. The International Monetary Fund (IMF) projected the world economy and the ASEAN 5 (Indonesia, Malaysia, the Philippines, Singapore, and Thailand) to contract sharply by –4.9% and −2.5% respectively in 2020, much worse than during the 2008–2009 financial crisis (IMF, 2020). Such an economic downturn is contracting energy demand and energy-related carbon dioxide (CO_2) emissions around the globe, but this crisis is seen as temporary and both energy demand and CO_2 emissions will bounce back once the economy starts to recover. Global energy demand increased 10 times from 1999 to 2019, and keeps increasing (IEA, 2017. The gravity of energy demand has shifted to Asia, and emerging economies account for half of global growth in gas demand. Many of the Organisation for Economic Co-operation and Development (OECD) countries will see energy demand peak, while some countries will experience negative growth due to energy efficiency and other factors such as population growth and industrial structures. However, ASEAN will be the opposite, as it will need more energy to steer its economic growth.

ASEAN will see strong growth in fossil fuel demand to steer economic growth from 2017[1] to 2050. Fossil fuels (oil, coal, and gas) had the dominant share in the primary energy mix in 2017, at 78.0%, while their combined share is projected to increase to 81.7% in 2050 (Annex Tables 1–9). Oil will be the largest energy source in the primary energy mix in 2050, at 39.6%, down from 36.9% in 2017. Coal was the second largest energy source after oil in 2017, at 21.6%, and is

[1] The energy modelling uses 2017 for the baseline information as it is the most up-to-date baseline data in the ASEAN Member States (AMS).

projected to have a 22.4% share in 2050. Natural gas is projected to have the second largest share of the primary energy mix in 2050, at 24.7%, overtaking coal.

In ASEAN, for the business-as-usual (BAU) scenario, oil was the main source of energy in the industry and transport sectors, at 30.8% and 26.8% respectively, in 2017 (Annex Tables 1–8). However, oil will have the largest share in the transport sector in 2050, at 35.6%, followed by industry, at 33.4%. Total power generation is projected to grow by 3.7% per year on average from 1,041 terawatt-hours (TWh) in 2017 to 3,439 TWh in 2050. Gas had the largest share of power generation in 2017, at 39.7%, and is projected to retain its spot in 2050, at 46.0%. Coal provided 36.6% of power generation in 2017, the second largest share after gas, but is projected to decrease to 35.5% in 2050. The share of hydropower was 17.6% in 2017, but is projected to drop to 10.4% in 2050 as hydropower resources are tapped to their potential. Geothermal energy had a 2.2% share in 2017 which is projected to decline to 2.1% in 2050. The remaining share (wind, solar, and biomass) was 1.4% in 2017, rising to 5.4% in 2050. However, in the alternative policy scenarios (APSs),[2] the share of solar, wind, and biomass is projected to reach 12.3%. Further, under the APS using the emission target of reducing emission by 80% in 2050, the share of solar, wind, and biomass will rise to 17.8% in 2050.

While the world, especially the OECD, moves away from fossil fuel dependence to a system based on cleaner energy through a higher share of renewables, ASEAN needs to consider how to use fossil fuels more cleanly in an energy transition. For instance, coal use has been drastically reduced in the OECD and more developed countries due to the role of gas, renewables, and advanced technologies. However, as the most abundant and reliable energy resource in ASEAN, coal use will continue to be the second largest energy source in power generation after gas in the foreseeable future, to meet fast-growing electricity demand. The increase in coal use for power generation in ASEAN countries will lead to the widespread construction of coal-fired power plants, which will result in increased greenhouse gas (GHG) and CO_2 emissions if the best available clean coal technology (CCT) is not employed (Phoumin, 2015).

[2] 'APSs' refers to all scenarios (the APS and scenarios 1 to 3 (APS_RE, APS_EI, and APS_EmT)).

Meanwhile, the climate narrative which has prevailed since the Conference of the Parties (COP) 21 in 2015 and is likely to continue at the upcoming COP 26, promotes the banning of public coal financing throughout the world, through financial instruments and influence over multilateral development banks and OECD member countries. Actions taken to abate CO_2 and GHG emissions have gained momentum in the developed world, especially the OECD, but developing nations cannot afford the available technologies to reduce such emissions. Further, China is leading the financing of coal-fired power plants in the developing world as it is not bound by the OECD's rules and obligations to ban coal financing. If not paired with more sustainable energy development, it is a real concern that increasing coal use in emerging Asia will have negative effects on the region's environmental security. With the projected increase in coal-fired generation capacity, both local pollutants – CO_2 and GHG emissions – will become major issues in the future. Based on the Greenhouse Gas Emissions Data (United States Environmental Protection Agency, 2020), emissions from fossil fuel combustion and industrial processes contributed about 78% of the increase in GHG emissions from 1970 to 2011. China, the United States (US), Europe, and India are the largest emitters, contributing 30%, 15%, 9%, and 6% of global GHG emissions, respectively. With substantial new generation capacity required to generate power, unabated coal-fired power generation plants are increasingly being constructed in developing Asia. These trends reflect the urgent need to address the environmental sustainability of powering emerging Asia's economic development.

Managing the energy transition in ASEAN will need to consider the presence of fossil fuels (coal, oil, and natural gas) in the short- and medium-term energy system. It will be crucial to explore ways in which to use fossil fuels in an environmentally sustainable manner to act as a bridge to a carbon-free energy future, rather than simply ruling out them completely. For successful implementation of the energy transition and climate change policy objectives, policymakers will need to balance the other equally important policy objectives of energy security, energy access, and affordability. For instance, the policy blind of banning public financing of CCT could be counterproductive in terms of climate mitigation since the lack of finance for highly efficient but more expensive CCT would simply result in the deployment of cheaper and less efficient technologies such as critical or subcritical technology of coal-fired power plants and more CO_2 emissions.

ASEAN's shift towards a cleaner energy system will have fundamental impacts on environmental sustainability. The pace at which ASEAN Member States (AMS) have adopted national power development plans and policies has created a drastic change in the energy system, as more renewables have penetrated the electrical grid. One of the greatest challenges of increasing the share of variable renewable energy (e.g. wind and solar) in the power mix is the high cost of upgrading and integrating the systems that need more investment in grids, the internet of things, technological know-how, and quality energy infrastructure. Creating a bridge from the current energy system to a cleaner energy system will need to consider the role of cleaner use of fossil fuels and the innovative technologies that can reduce CO_2 and GHG emissions. Therefore, urgent steps need to be taken to decarbonise the energy sector through pathways to a low-carbon economy which require the rapid deployment of the clean use of fossil fuel technologies, renewable energy development, and a doubling of energy efficiency, given that the energy sector accounts for two-thirds of global GHG emissions. Thus, policy towards energy security and affordability will need to be flexible, considering the role of fossil fuels in an energy transition. To meet the growing energy demand, appropriate energy policies and cooperation are needed to facilitate energy-related infrastructure investments. These common energy challenges need to be addressed through concerted efforts – including collective measures and actions – to rapidly deploy energy efficiency and energy savings, highly efficient and low-emissions coal-fired power plant technology, and nuclear safety; and to double the share of renewable energy in the overall energy mix for inclusive and sustainable development.

The objective of this study is to explore the best energy mix under various APSs and the associated emissions. Under the APS, key considerations are realistic assumptions in terms of technologies, resource endowment, energy efficiency, and system integration challenges, when the power generation mix has a higher share of intermittent renewables such as wind and solar energy. The paper is organised as follows. Section 2 reviews the literature, section 3 discusses the research methodology, section 4 describes the results and discussion, and section 5 concludes and presents the policy implications.

2. Literature Review

2.1. Global Commitment to Emissions Reduction (COP 21)

The Paris Agreement, negotiated at the Paris Climate Conference (COP 21), is the first universal legally binding global climate change agreement, adopted by the majority of leaders on 22 April 2016. It aims to limit the average temperature rise to well below 2°C above pre-industrial levels (baseline: 1850–1900) and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change (EU, 2020).

Bridging the gap from current policies and actions to climate neutrality by the end of this century is very challenging. The world will need to reduce emissions by 7.6% per year from 2020 to 2030 to limit global warming to 1.5°C. If we do nothing, temperatures are expected to rise 3.2°C above pre-industrial levels by the end of century – posing a serious threat to our living environment (UNEP, 2019). If emissions cuts are delayed, it will become very difficult to meet the limit of a global temperature rise of well below 1.5°C by 2100. UNEP (2019) stated that delaying emissions cuts until 2025 would steepen the need to cut emissions to 15.5% per year, which would be extremely difficult to achieve, especially for the developing world. As parties to the Paris Agreement, countries have submitted comprehensive national climate action plans known as Nationally Determined Contributions (NDCs). Some countries have not yet finalised their NDCs, but have carried out preparatory work known as Intended Nationally Determined Contributions (INDCs).

About 78% of all global emissions come from G20 nations, requiring their strong commitment to long-term zero emissions targets by 2100. Amongst the G20 nations, China, the US, the European Union (EU) 28,[3] and India contributed more

[3] The EU 28 refers to the 28 countries which were members of the EU until 31 January 2020 when

than 55% of the total emissions over the last decade (UNEP, 2019). Thus, the speed of emissions reduction is very concerning, and full decarbonisation of the energy sector may go beyond renewables and energy efficiency. The carbon sinks will rely on the clean use of fossil fuels with carbon capture, utilisation, and storage (CCUS). Developing countries may face difficulties in achieving emissions reduction targets without international support, such as technologies for the clean use of fossil fuels and the other climate abatement initiatives. However, their emissions contribution remains small compared with that of the G20 nations. Developing nations can contribute more in terms of the conservation of natural resources such as forestry and the management of improved agricultural practices.

2.2. ASEAN and EU Energy Policy Directions

Phase 2 of the ASEAN Plan of Action for Energy Cooperation (APAEC), which is under preparation for endorsement by the ASEAN Ministers on Energy Meeting in 2020, will set key energy policy targets and will have energy policy implications for energy infrastructure related investment in the region (ASEAN Centre for Energy, 2020). Key targets include the revision of the new energy efficiency and conservation target from a 30% reduction in energy intensity by 2025 (based on 2005 levels) to more ambitious levels – a new target of 35%–40% reduction is likely – and will involve the expansion of energy efficiency and conservation measures to transport and industries. It will also establish a new sub-target for the share of renewables in installed power capacity, which will complement the existing target of a 23% share of renewables in the total primary energy supply (TPES) by 2025. APAEC Phase 2 will also include policy measures to pursue smart grids and renewable energy grid integration; and measures to address emerging and alternative technologies such as hydrogen, energy storage, bioenergy, nuclear energy, and CCUS. APAEC Phase 2 will maintain the focus on energy connectivity and market integration, but will add a sub-theme on the energy

the United Kingdom left the group (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovenia, Slovakia, Spain, Sweden, and United Kingdom).

transition and energy resilience on how the region will need to have a strategy to deal with fossil fuels and new technologies.

The ASEAN region has wide economic development gaps in terms of gross domestic product (GDP), population growth, energy use, and technologies. However, each country is committed to addressing the common climate change issue. Countries share their commitments through various policies such as energy intensity targets or through targets for the share of renewables in the energy mix. Nevertheless, emerging countries face energy access and affordability issues, while promoting renewables and other clean energy technologies remains expensive. Although solar and wind module costs have dropped drastically, the system cost remains expensive when applied in developing countries. Making these clean and green technologies available to developing countries in ASEAN will require policy attention, including regulations and financing mechanisms, with support from developed countries.

The EU aims to be climate neutral by 2050 (EU, 2020). Amongst other targets, the 2030 climate and energy framework includes EU-wide targets and policy objectives for 2021–2030. The key targets for 2030 include (i) at least 40.0% cuts in GHG emissions from 1990 levels, (ii) at least a 32.0% share for renewable energy, and (iii) at least a 32.5% improvement in energy efficiency. For GHG emissions, a cut of at least 40.0% below 1990 levels is targeted by 2030. This will enable the EU to move towards a climate-neutral economy and implement its commitments under the Paris Agreement. For renewables, the binding renewable energy target for the EU for 2030 is at least 32.0% of final energy consumption, including a review clause by 2023 for an upward revision of the target. For energy efficiency, a headline target of at least 32.5% is to be achieved collectively by the EU in 2030, with an upward revision clause by 2023. To help achieve these targets, a transparent and dynamic governance process will help deliver on the 2030 climate and energy targets in an efficient and coherent manner. The EU has adopted integrated monitoring and reporting rules to ensure progress towards its 2030 climate and energy targets and its international commitments under the Paris Agreement.

2.3. Review of INDCs' Emissions Reduction Commitments and Targets by ASEAN Member States

COP 21 was a very successful conference, at which leaders around the globe showed their solidarity in fighting global climate change. Countries laid out targets or programmes aimed at reducing CO_2 emissions. Some countries have clear policies and targets, while others have no targets – especially developing countries. In the AMS, the key commitments are varied, reflecting each country's socio-economic and environmental situation. The following paragraphs summarise the key commitments of AMS for mitigating climate change (Kimura and Phoumin, 2018).

Cambodia proposes a GHG mitigation contribution for 2020–2030 (UNFCCC, 2015), conditional on the availability of support from the international community. Cambodia is expected to contribute a maximum reduction of 3,100 gigagrams of carbon dioxide equivalent ($GgCO_2eq$) by 2030 compared with 2010 baseline emissions of 11,600 $GgCO_2eq$. The Lao People's Democratic Republic (Lao PDR) is a highly climate-vulnerable country whose GHG emissions were only 51,000 $GgCO_2eq$ in 2000 – negligible compared with total global emissions. The Lao PDR has ambitious plans to reduce its GHG emissions through increased carbon stock by expanding forest cover to 70% of the country's land area by 2020. The Lao PDR electricity grid draws on renewable resources for almost 100% of output, and the government has laid the foundations for implementing a renewable energy strategy that aims to increase the share of small-scale renewable energy to 30% of total energy consumption by 2030.

Viet Nam's intended unconditional contribution[4] to GHG emissions reduction efforts during 2021–2030 is to reduce its GHG emissions by 8% in 2030 compared with the BAU scenario, in which the emissions intensity per unit of GDP will decline by 20% from 2010 levels and forest coverage will increase by 45%. Under its conditional contribution, Viet Nam intends to cut emissions by 25% from 2010 levels if international support is received through bilateral and multilateral

[4] Developing countries announced two sets of mitigation targets to be reached under the Paris Agreement. The low target or unconditional target can be reached without outside support. However, the conditional target can be reached only with outside support.

cooperation (UNFCCC, 2015). Further, the emissions intensity target per unit of GDP will be reduced by 30% from 2010 levels. Thailand expects its GHG emissions to reach 555 million tonnes of carbon equivalent ($MtCO_2e$) by 2030 in the BAU case, with 76.8% mainly from the energy and transport sectors. According to Thailand's INDC, the country intends to reduce GHG emissions by 20% of the BAU emissions in 2030. This means that Thailand's amount of GHG emissions reduction should be 111 $MtCO_2e$ in 2020.

From 2016 to 2030, Myanmar aims to increase the share of renewables in rural electrification to 30%, increase hydropower capacity to 9.4 gigawatts, and distribute about 260,000 energy-efficient cooking stoves to rural areas (UNFCCC, 2015). For energy efficiency, Myanmar aims to achieve 20% electricity-saving potential of the forecast electricity consumption by 2030. Under the INDC framework, Brunei Darussalam targets reducing its energy consumption by 63% by 2035 against the BAU scenario. Furthermore, the country aims to achieve a 10% share of renewable energy in power generation by 2035. With regards to the transport sector, the target is to reduce CO_2 emissions by 40% from morning peak-hour vehicle use by 2035 compared with the BAU scenario. Another target in its INDC is to enhance the stocks of carbon sinks by increasing the current 41%–55% of the country's total forest area in 2016.

Indonesia's INDC specifies conditional and unconditional mitigation targets. It intends to reduce 29% of its emissions against the BAU scenario by 2030 in the unconditional scenario. If there is additional international support, Indonesia intends to reduce an additional 12% of the emissions. The intended contributions cover five sectors: energy (including transport); industrial processes and product use; agriculture; land use, land use change, and forestry; and waste. The amount of emissions under the 29% and 41% reduction targets would be 0.848 $GtCO_2eq$ and 1.119 $GtCO_2eq$, respectively. Malaysia intends to reduce its GHG emissions intensity of GDP by 45% by 2030 relative to the emissions intensity of GDP in 2005 (UNFCCC, 2015). This consists of 35% on an unconditional basis and a further 10% conditional upon receipt of climate finance, technology transfer, and capacity building from developed countries.

The Philippines targets a GHG emissions reduction of 70% by 2030 relative to its BAU scenario of 2000–2030. The mitigation contribution is conditioned on the extent of financial resources – including technology development and transfer – and capacity building that will be made available to the Philippines (Kimura and Phoumin, 2018). Singapore pledged in 2009 to reduce carbon emissions unconditionally from 7%–11% lower than its BAU level by 2020. It committed to a further 16% reduction by 2020 after the COP 21 in Paris on 12 December 2015.

3. Methodology and Scenario Assumptions

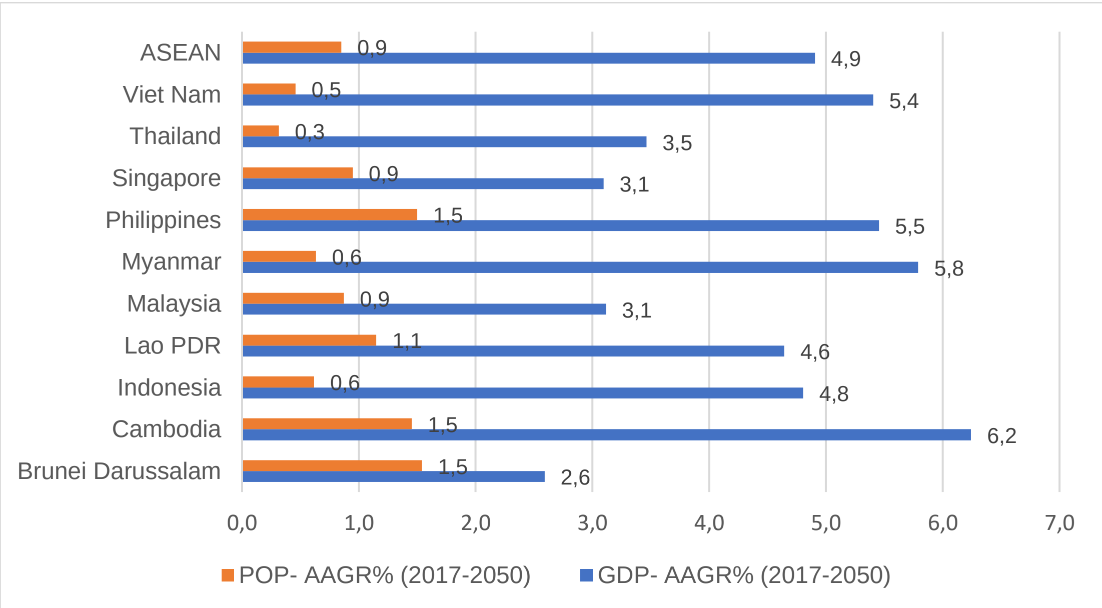
The energy models of ASEAN countries were developed using the Long-range Energy Alternatives Planning (LEAP) system software, an accounting system used to develop projections of energy balance tables based on final energy consumption and energy input/output in the transformation sector. Final energy consumption is forecast using energy demand equations by energy and sector and future macroeconomic assumptions. The macroeconomic module also 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 from the macroeconomic module. An econometric approach means that future demand and supply will be heavily influenced by historical trends. However, the supply of energy and new technologies is treated exogenously. For electricity generation, the respective ASEAN countries provided specific assumptions to determine the future electricity generation mix based on each national power development plan.

Historical data and their availability vary in the 10 AMS. It is very challenging to collect long-term historical data in countries such as Cambodia, the Lao PDR, and Myanmar. Further, there are many missing data points in the historical data that need to be estimated. The LEAP application is very useful in dealing with such minimal data, and it allows expert judgement on how the future growth of demand in each fuel should be estimated. If good historical data are available, linear forecasting is used to forecast future values based on a time series of historical data. The new values are predicted using linear regression, assuming a linear trend ($y = mx + c$) where the Y term corresponds to the variable to be forecast and the X term is years. Multiple regressions are used to predict the future growth of energy demand by sector, such as transport, industry, and the commercial and residential sectors.

In this modelling work using the LEAP application, the baseline for the 10 AMS was 2017 – the latest available baseline data. For future energy demand, the projected demand growth is based on government policies, population and economic growth, and other key variable such as energy prices, using the International Energy Agency (IEA) world energy model (IEA, 2019). The BAU case is future predicted energy demand based on the government's current energy policies. However, the APSs are somewhat different to the BAU case in terms of policy changes and targets, as they have a greater share of renewables, including possible nuclear uptake if the government's alternative policies include nuclear as an energy option and more efficient power generation and energy efficiency in the final energy consumption.

Key variables and assumptions used in the model include the average annual growth rate of the population and the GDP, and energy efficiency and renewable targets (Figure 1).

Figure 1: Average Annual Growth Rate of GDP (%) **and Population in AMS, 2017–2050**



AMS = ASEAN Member States, ASEAN = Association of Southeast Asian Nations, GDP-AAGR = average annual growth rate of GDP, POP-AAGR = average annual growth rate of the population.
Source: Authors' calculations.

In this study, the BAU scenario assumes that past developments, current energy demand, and technologies will affect future demand. However, the study also developed several APSs based on various assumptions – e.g. changes in policies such as a higher share of renewables in the energy mix; changes in energy intensity as a result of economic structural changes towards more efficient energy consumption per unit of GDP; technological developments in terms of thermal efficiency and final energy efficiency applications in the industrial, transport, commercial, and residential sectors; and other targets towards stronger policy in emissions reduction targets. The APSs are as follows:

- **APS.** The APS uses the assumptions of more efficient final energy consumption, more efficient power generation, a higher share of renewables, and the introduction of nuclear power plants, based on each AMS government policy. The assumptions used in the APS are described in the table below.
- **APS_RE.** The APS_RE is the APS with a higher share of renewable targets at the ASEAN level. In the APS_RE, the targets are increases of 23%, 30%, and 50% in the share of renewables in the primary energy supply by 2025, 2030, and 2050, respectively, from 2005 levels. The increase in the renewable share is expected from solar, wind, geothermal, and hydro. As hydro and geothermal energy are limited by resources, the maximum share is set based on the resource endowment.
- **APS_EI.** The APS_EI is the APS using energy intensity reduction targets of 30%, 40%, and 50% from 2005 levels by 2025, 2030, and 2050, respectively. A greater reduction in energy intensity means that the energy consumption per unit of GDP becomes more efficient as a result of the application of energy efficiency, technological development, or any economic structural transformation of the economies shifting from energy-intensive sectors such as industry to less energy-intensive sectors such as services.
- **APS_EmT.** The APS_EmT is the APS using emission reduction targets of 40% and 80% from the BAU scenario by 2030 and 2050, respectively. This is the top–down policy target in which the energy mix composition needs to be changed towards cleaner energy to meet such targets. This will have many

policy implications if the AMS wish to reduce emissions by as much as half from the BAU scenario by 2050.

Table 1: Other Assumptions of Energy Saving Targets under the APS by AMS

Country	Assumptions
Brunei Darussalam	Electricity: 35% reduction target by 2050
Cambodia	Specific fuel efficiency target by 2050 included (coal, oil, gas, biomass industry, 10%; electricity efficiency target, 20%)
Indonesia	Sectoral target by 2050 (commercial and residential, 10%; transport, 20%; bioethanol blending increase to 15% from 3%–7% in 2010)
Lao PDR	Biodiesel: 20% blend from 1%–5% in 2010; utilisation of biofuels equivalent to 10% of road transport fuels
Malaysia	16% electricity saving by 2050 in industry, commercial, and residential sectors; 16% oil saving in final consumption by 2050; replacement of 5% of diesel in road transport with biodiesel
Myanmar	Target saving by 2050 included (transport and residential by 20%; industry, commercial, and others by 10%); replacement of 8% of transport diesel with biodiesel
Philippines	20% saving of oil and electricity by 2050; displacement of 20% of diesel and gasoline with biofuels by 2025
Thailand	Energy efficiency targets by 2050 included (transport, 70%; residential, 10%; commercial, 40%; and industry, 20% reduction of final energy demand); biofuels to displace 12.2% of transport energy demand
Viet Nam	20% reduction for all sectors; 10% ethanol blend in gasoline for road transport

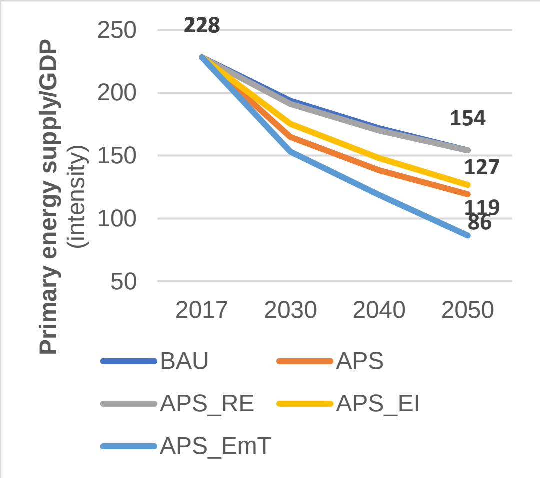
AMS = ASEAN Member State, APS = alternative policy scenario, ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic.
Source: Kimura and Phoumin (2019).

4. Results and Analyses

The results of various energy supply and demand scenarios in ASEAN are in Annex Tables 1–8. ASEAN's energy system is predicted to be more efficient because energy intensity is expected to drop from the baseline in the future scenarios. However, the energy system will largely depend on fossil fuel consumption. The results from the energy model predicted that all ASEAN's emissions in the future scenarios will remain high because fossil fuel remains the dominant share in the future energy mix. Fossil fuel consumption – coal, oil, or natural gas – is associated with emissions, although natural gas has less emissions than coal and oil. It is also important to note that the trend of natural gas use in the energy transition is very promising, as its share has grown quickly in the primary energy mix as well as in power generation. Thus, ASEAN's energy transition will need to consider cleaner use of fossil fuels through clean technologies and a gradually increasing share of renewables and clean energy. Any policy changes to meet the emissions reduction in ASEAN need to be cautioned about high energy costs, energy access, affordability, and energy security risks. Below are the key results from the study.

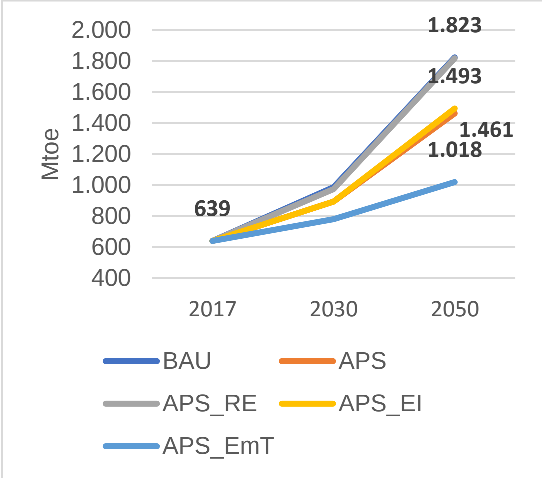
More efficient use of energy. ASEAN's primary energy supply grows at an annual average rate of 3.1% from 2017 to 2050 under the BAU scenario, reaching 1,823 million tonnes of oil equivalent (Mtoe) in 2050 from 639 Mtoe in 2017 (Figure 3). However, under the APS of ambitious emissions reduction targets (APS_EmT), the primary energy supply is predicted to reduce by 21% and 44% from the BAU in 2030 and 2050, respectively (Annex Tables 1 and 2). ASEAN as a group achieves a significant reduction in energy intensity of 30.3% in the BAU case (a drop of energy intensity from 228 in 2017 to 154 in 2050). However, the scenario of emissions reduction targets (APS_EmT) could achieve a reduction of 60% in energy intensity in 2050 from the BAU scenario (a drop of energy intensity from 228 in 2017 to 86 in 2050) (Figure 2).

Figure 2: Energy Intensity in ASEAN



APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, ASEAN = Association of Southeast Asian Nations, BAU = business as usual, GDP = gross domestic product.
Source: Authors' calculations.

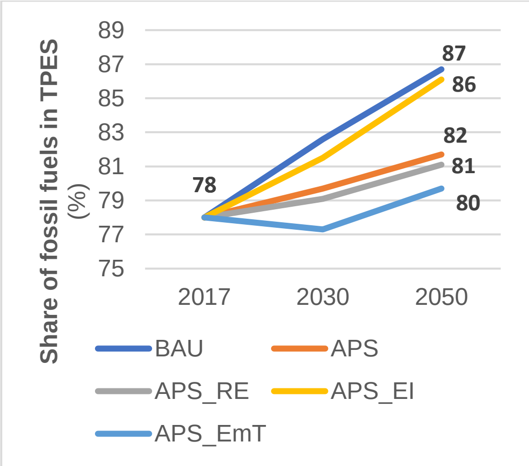
Figure 3: Primary Energy Supply (TPES) in ASEAN



APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, ASEAN = Association of Southeast Asian Nations, BAU = business as usual, Mtoe = million tonnes of oil equivalent, TPES = total primary energy supply.
Source: Authors' calculations.

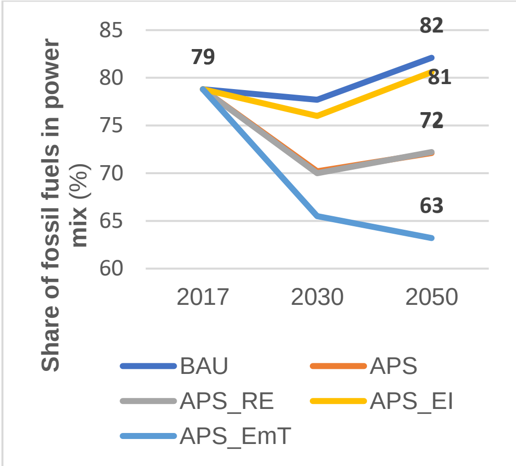
Reliance on fossil fuel consumption. The results from the energy demand and supply modelling under various policy scenarios draw attention to the high reliance on fossil fuel use in ASEAN's energy system. The total combined share of fossil fuels (oil, gas, and coal) in the primary energy supply was 78% in 2017; and they are predicted to have an 87%, 82%, and 80% share in 2050 under the BAU, APS, and APS with emission reduction targets (APS_EmT) scenarios, respectively (Figures 4 and 5).

Figure 4: Share of Fossil Fuels (Coal, Oil, Gas) in the TPES



APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, BAU = business as usual, TPES = total primary energy supply.
Source: Authors' calculations.

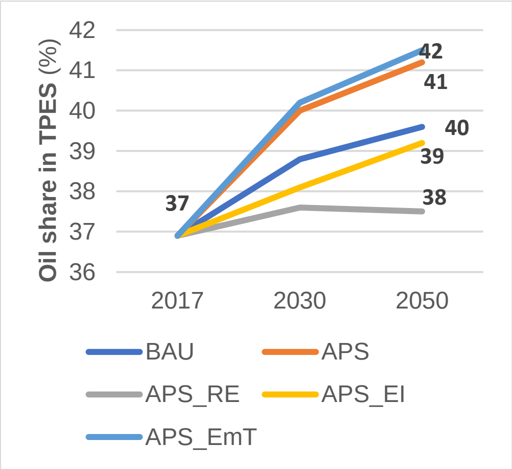
Figure 5: Share of Fossil Fuels in the Power Mix



APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, BAU = business as usual.
Source: Authors' calculations.

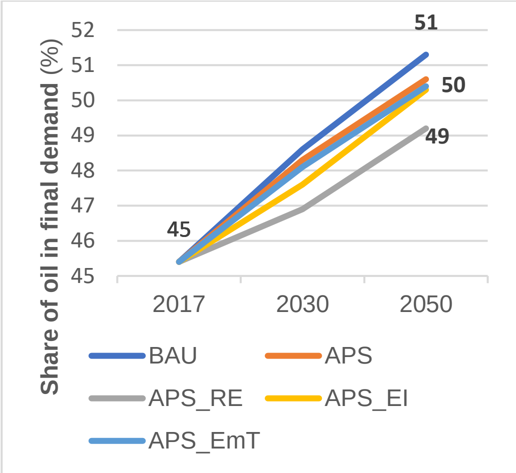
Oil remains the dominant fuel in the primary energy supply, with a share of 37% in 2017. The share of oil is projected to be 42%, 41%, and 38% in the BAU scenario, APS, and APS_EmT in 2050, respectively (Figures 6 and 7). Oil is mainly used in the transport and industrial sectors in the final energy demand. The share of oil in the final energy demand was 45% in 2017, and its share grows to 51%, 50%, and 49% in 2050 for the BAU scenario, APS, and APS_EmT, respectively. This indicates that ASEAN as a group will rely heavily on oil consumption for the foreseeable future. For most countries in ASEAN, the growing oil import dependency will need to be safeguarded by resilient infrastructure and mechanisms such as oil stockpiling (either government stock or inventory stock by the oil importing companies). Most countries in ASEAN have a stock requirement of 15–50 days, varying from country to country. However, the stock requirement for OECD members will need to be at least 90 days of net oil imports to meet the emergency oil stock holding requirement in case of supply disruption (IEA, 2020).

Figure 6: Oil Share in TPES in ASEAN



APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, ASEAN = Association of Southeast Asian Nations, BAU = business as usual, TPES = total primary energy supply.
Source: Authors' calculations.

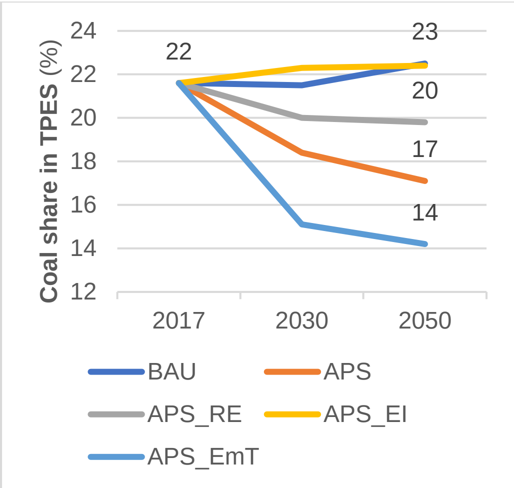
Figure 7: Oil Share in Final Demand in ASEAN



APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, ASEAN = Association of Southeast Asian Nations, BAU = business as usual.
Source: Authors' calculations.

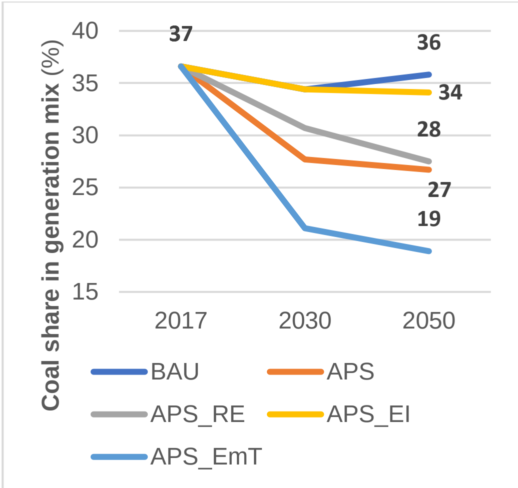
The share of coal in the primary energy supply was 22% in 2017; and it is predicted to be 23%, 17%, and 14% in the BAU scenario, APS, and APS_EmT in 2050, respectively. Coal has the second largest share in power generation, at 37% in 2017; and it is predicted to be 36%, 27%, and 19% in the BAU scenario, APS, and APS_EmT in 2050, respectively. Under the APS of emission reduction targets (APS_EmT), the share of coal is projected to drop significantly for both the primary energy supply as well as the share in the power generation mix (Figures 8 and 9).

Figure 8: Coal Share in TPES in ASEAN



APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, ASEAN = Association of Southeast Asian Nations, BAU = business as usual, TPES = total primary energy supply.
Source: Authors' calculations.

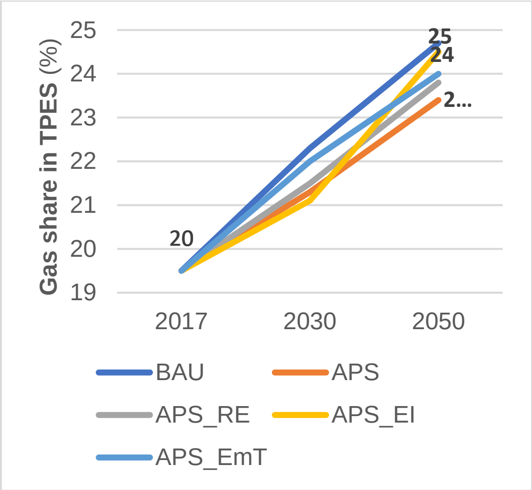
Figure 9: Coal Share in Generation Mix in ASEAN



APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, ASEAN = Association of Southeast Asian Nations, BAU = business as usual.
Source: Authors' calculations.

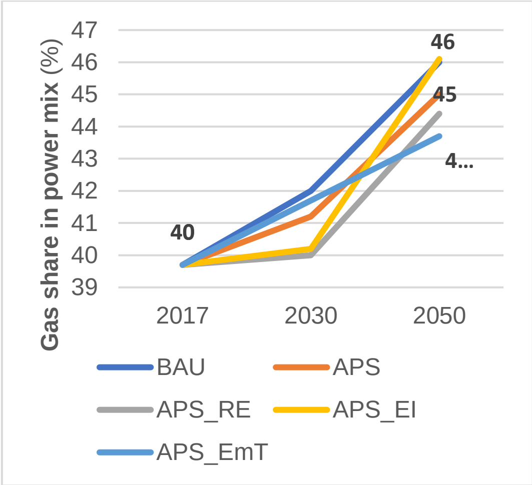
Although ASEAN relies heavily on fossil fuels (oil, coal, and gas), some AMS have shifted drastically to use more gas in power generation and other final uses, such as the industrial and transportation sectors. ASEAN as a group had a 20% share of gas in the primary supply in 2017, but its share in the primary energy supply is projected to increase to 25% and 23% in 2050 for the BAU case and APS, respectively. Remarkably, the share of gas, at 40% in 2017, was a dominant fuel in the power generation mix; and it is projected to increase to 46%, 45%, and 44% in 2050 for the BAU case, APS, and APS_EmT, respectively.

Figure 10: Gas Share in TPES in ASEAN



APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, ASEAN = Association of Southeast Asian Nations, BAU = business as usual, TPES = total primary energy supply.
Source: Authors' calculations.

Figure 11: Gas Share in Generation Mix

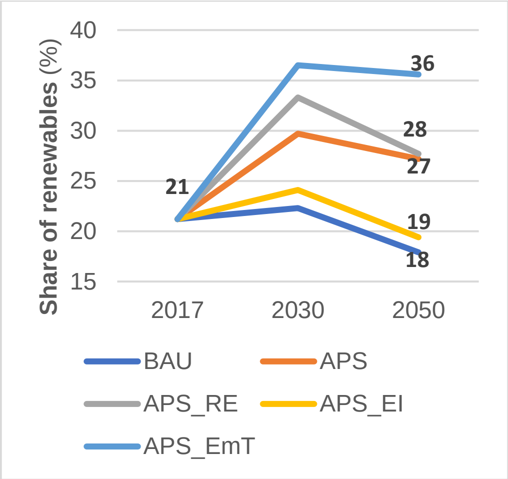


APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, ASEAN = Association of Southeast Asian Nations, BAU = business as usual.
Source: Authors' calculations.

Increasing but not sufficient share of renewables. The share of renewables (hydropower, geothermal, biomass, wind, and solar) in the power mix was 21% in 2017. Its share is projected to increase to 36%, 28%, and 27% in the APS_EmT, APS_RE, and APS in 2050 (Figure 12). The share of renewables is projected to be higher in 2030 than 2050 because hydropower and geothermal resources are limited. However, the share of wind and solar is projected to increase from 2% in 2017 to 18%, 12%, and 11% in 2050 under the APS_EmT, APS_RE, and APS, respectively (Figure 13).

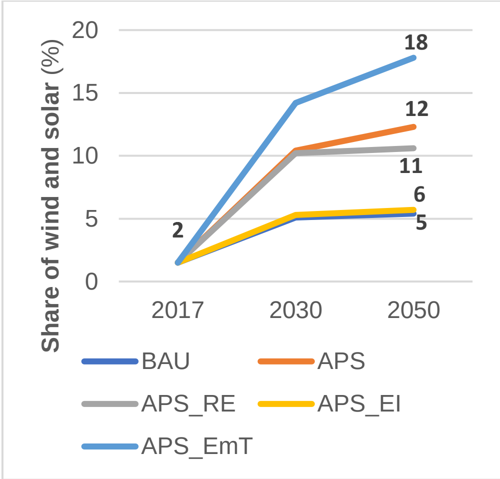
Although renewables are key to achieving emissions reductions, their share in the energy mix is not high enough to decarbonise emissions to meet the climate target of reducing emissions to net zero from 2050 until the turn of this century (Figures 14 and 15).

Figure 12: Renewables Share in Power Mix



APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, ASEAN = Association of Southeast Asian Nations, BAU = business as usual.
Source: Authors' calculations.

Figure 13: Share of Wind and Solar in Power Mix

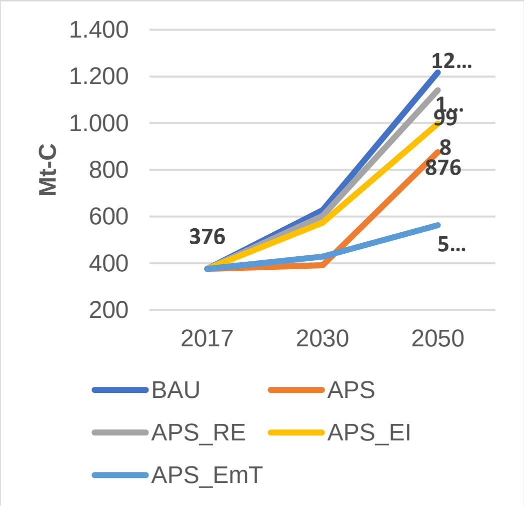


APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, ASEAN = Association of Southeast Asian Nations, BAU = business as usual.
Source: Authors' calculations.

Achieving the APS_EmT is very unlikely because this scenario assumes the most efficient technologies and the highest share of renewables to achieve emissions reduction targets. Although the emissions reduction target was set at 80% from the BAU scenario to the APS_EmT, given the plausible challenges of integrating wind and solar in ASEAN's system, only 55% could be achieved for all combined types of renewables. Thus, the remaining emissions coming from fossil fuels will need to be decarbonised through CCUS technologies or the growth of natural carbon stock.

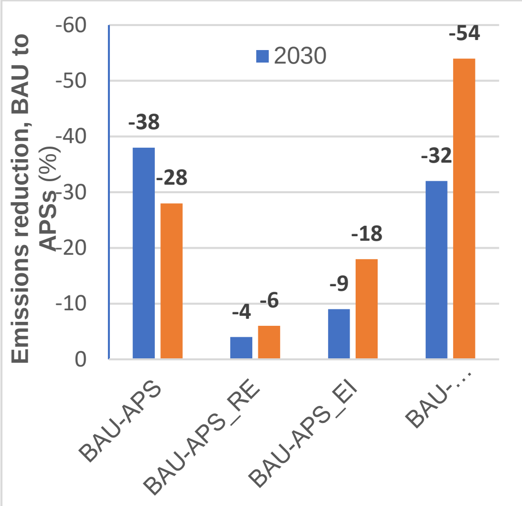
ASEAN's emissions keep increasing in the foreseeable scenarios. ASEAN as a group will see emissions doubling or tripling from 2017 to 2050, varying from the BAU case to the APSs. In the BAU scenario, emissions could reach 1,217 million tonnes of carbon (Mt-C), almost triple the baseline level of 376 Mt-C in 2017. However, emissions could also be lower, at 876 Mt-C for the APS and 563 Mt-C for the APS_EmT (Figure 14). To limit the global temperature rise to 1.5°C by 2100, emissions will need to be slashed by 45% from 2010 levels by 2030, then reach net zero emissions by 2050 (The Climate Reality Project, 2018). Thus, ASEAN as a group will miss this target and it will make it more difficult to cut emissions by 2050.

Figure 14: Emission Reduction in Various Scenarios



APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, ASEAN = Association of Southeast Asian Nations, BAU = business as usual.
Mt-C = million tonnes of carbon.
Source: Authors' calculations.

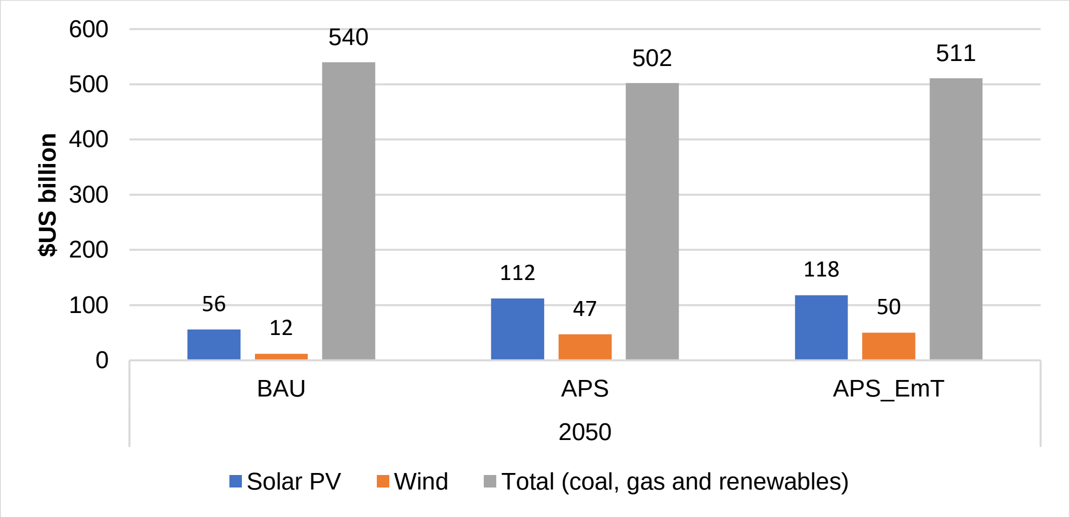
Figure 15: Emission Reduction in the Power Mix



APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, ASEAN = Association of Southeast Asian Nations, BAU = business as usual.
Source: Authors' calculations.

Required investment in power generation. Figure 16 is the estimated required investment for solar and wind energy. Accelerating the share of variable renewables, such as solar and wind, in ASEAN's power mix will require \$56 billion–\$118 billion from the BAU scenario to the APSs in the case of solar photovoltaic and \$12 billion–\$50 billion in the case of wind, in 2050 (Figure 16). The total investment in the power generation of additional capacity will be \$540 billion in the BAU scenario and \$511 billion in the APSs – reflecting the reduced investment in fossil fuels and the increase in renewables, which will have less capital costs, driven by technological development, expected in 2050.

Figure 16: Required Investment for Variable Renewable Energy (Solar and Wind) by 2050



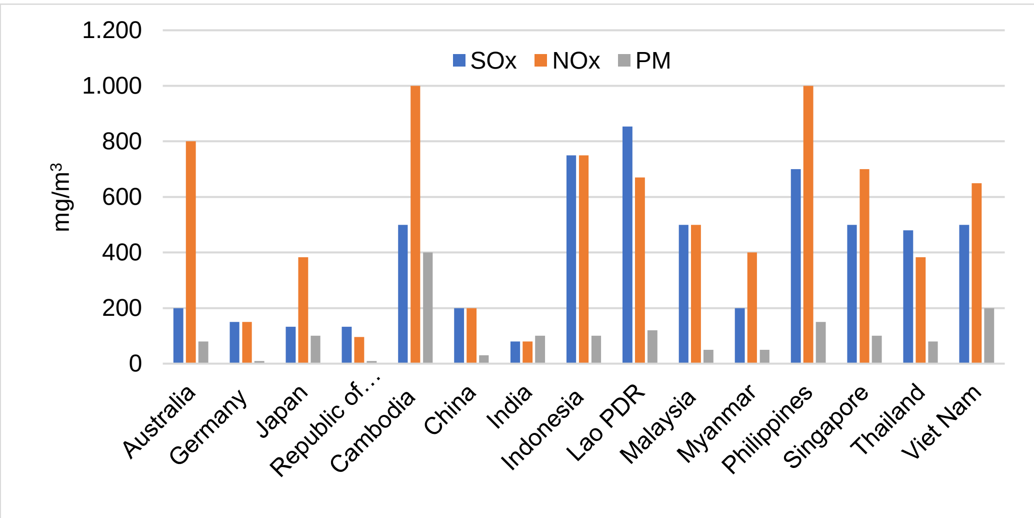
APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, ASEAN = Association of Southeast Asian Nations, BAU = business as usual.
Source: Authors' calculations.

5. Implications of the Scenario Results

In 2020, fossil fuels (oil, coal, and natural gas) have the largest share of ASEAN's primary energy mix, at 78%. They are expected to continue to have a dominant share in the BAU scenario in 2050, at 86%, but could drop slightly to an 82% and 80% share under the APS and APS emission reduction target (APS_EmT) respectively in 2050, when considering more efficient power generation, an increasing share of renewables, and energy efficiency measures (Annex Tables 1–9). Although oil has the largest share in the primary energy mix, natural gas and coal are the dominant energy sources in the power generation mix, at 37% and 44% respectively in 2017; and their share is projected to be 46% and 36% respectively in 2050.

Need for cleaner use of fossil fuels and clean technologies. The composition of the future energy system depends on the current actions, policies, and future policy changes. However, all decisions need to be weighed against potentially higher energy costs, affordability, and energy security risks. Coal consumption has dropped globally in recent years, but Southeast Asia has seen the opposite trend – coal consumption has been concentrated in power generation although its share of the primary energy supply remains the same from the BAU scenario to the APS, while the actual quantity of coal consumption is predicted to increase significantly from 143 Mtoe in 2017 to 251 Mtoe in 2050. The relatively high level of coal consumption in ASEAN could be attributable to affordability and energy security issues. As coal will be the second most dominant source of energy for power generation, there is a real concern that many ASEAN countries cannot afford clean technologies such as CCT (advanced ultra-supercritical (A-USC) or ultra-supercritical (USC) technology) due to the higher up-front cost of these technologies compared with conventional high-emissions coal power plants (subcritical technology). At the same time, ASEAN as a bloc has lower emissions standards for coal-fired power plants than advanced countries such as Germany, Japan, and the Republic of Korea, where CCT is mandatory (Figure 17). This means that ASEAN countries have relatively high allowable emissions in terms of sulphur oxides (SOx), nitrogen oxides (NOx), and particulate matter (PM).

Figure 17: Emissions Standards for Newly Constructed Coal-Fired Power Plants in Selected Countries



Lao PDR = Lao People Democratic Republic, mg/m^3 = milligram per cubic metre, NOx – nitrogen oxides, PM = particulate matter, SOx – sulphur oxides.
Source: Motokura et al. (2017).

Promoting natural gas uses in ASEAN's energy transition. Natural gas has a significant role to play in ASEAN's transition to a cleaner energy system. ASEAN as a group is forecast to continue to be a net natural gas exporter until 2030, but the situation will change due to declining domestic natural gas production and increasing domestic energy demand in ASEAN (Kobayashi and Phoumin, 2018). Demand for liquefied natural gas (LNG) in ASEAN is driven by increasing demand from the power generation and industrial sectors. Most AMS will see rising LNG imports in the foreseeable future because of sustained growth in electricity demand, the public preference for a cleaner fuel, and depleting domestic production. Prospects for the use of natural gas in ASEAN are optimistic, and demand is likely to increase 3.5 times in the BAU case (from 129 Mtoe in 2027 to 450 Mtoe in 2050) – depending on the future stability of gas and LNG market prices, and whether ASEAN and East Asia can create a competitive gas/LNG market in the future, with potential supply of gas/LNG from Australia, US, and other sources. Thus, ASEAN is expected to be a key market for future gas demand, so investment in gas infrastructure (such as gas pipelines and LNG receiving terminals) is crucial to support the increasing demand for gas in ASEAN.

ASEAN's scaling up renewable share and adoption of smart grid. Energy sustainability in ASEAN and around the globe requires an increased share of renewables in the energy mix to decarbonise emissions. Currently, ASEAN's power generation mix is dominated by coal, gas, and hydropower (Annex Tables 1–8). Intermittent renewables (solar and wind) comprise the most abundant energy resources in ASEAN, but have contributed negligible amounts (1.4% in 2017, 2.4% in 2020, and 10% and 12% in 2050 for the APS) to the power mix. Many ASEAN grid operators hold misperceptions about intermittent renewable energy. Although the production cost of renewable energy has dropped dramatically in recent years, its share in the power generation mix remains small. The misperceptions about renewable energy stem from its variable and intermittent nature, which adds costs to grid systems as it requires back-up capacity from conventional gas power plants. Technically, wind and solar power output varies depending on the strength of the wind or the amount of sunshine. However, this risk of variable energy output can be minimised if power systems are integrated within countries and within the ASEAN region. The aggregation of output from solar and wind from different geographical locations has a balancing effect on the variability (NREL, 2020). However, the ASEAN Power Grid is making slow progress and the integrated

ASEAN power market may remain unrealised due to several reasons, such as regulatory and technical harmonisation issues between the ASEAN Power Grid and utilities.

Challenges of power system integration in ASEAN. In the recent development of the power mix in ASEAN, some countries have accelerated the increase in the share of solar in the power mix without properly considering the poor gird infrastructure and power system integration challenges. As a result, electricity from solar has been curtailed. It is important to note that the shift from fossil fuels towards renewables in the energy transition will involve costs and investments for all energy-related infrastructure, which will hugely affect energy affordability. For AMS that can afford significant investments in renewable energies, an important concern is the need for electricity storage and smart grids to support higher renewable energy penetration levels in the electricity sector. Smart grid technologies are already making significant contributions to electricity grids in some developed countries of the OECD. However, these technologies are undergoing continual refinement and hence are vulnerable to potential technical and non-technical risks. Renewable energy growth will thus be constrained by infrastructure development as well as by the evolution of technology, including the capacity to assess and predict the availability of renewable energy sources (Kimura, Pacudan, and Phoumin, 2017). These capacities of smart grids offer additional benefits, notably the promise of higher reliability and overall electricity system efficiency.

Long-term emissions reduction and COVID-19. Due to the drastic decline in energy consumption, daily global emissions dropped by 17% in the first quarter of 2020 compared with 2019 levels (Le Quéré et al., 2020). However, an economic recovery could see the levels of CO_2 emissions bouncing back very quickly. Indeed, global data from late May 2020 show an all-time high for CO_2 levels, as countries started to reopen their economies. The sudden drop in current emissions has nothing to do with low-carbon energy policy measures – it is just the impact of the pandemic slowing down all economic activities. It is also understandable that the energy structure cannot be changed overnight, given its large dependence on fossil fuels. The results have shown that ASEAN emissions will be 1,217 Mt-C in the BAU and

565 Mt-C to 876 Mt-C in the APSs, in which they are supposed to fall to zero emissions if the rise in temperature is to keep within 1.5°C by the end of this century. This means that ASEAN will not be able to achieve the emissions reduction targets. This necessitates a serious review of the commitment in the NDCs or INDCs to limit the emissions to half by 2030 and reach net zero emissions by 2050. It also points to the urgent need for carbon sink technologies such as CCUS.

ASEAN's energy transition from a system based on fossil fuels to a system based on cleaner energy use will rely on investment in quality infrastructure – including renewable and cleaner use of fossil fuels, and CCUS – to reduce global GHG emissions and avoid the most serious impacts of climate change. Clean technologies and CCUS are the obvious choice to reduce fossil fuel emissions in ASEAN, while accelerating the use of renewables and the application of energy efficiency in all sectors.

Need for quality energy infrastructure and investment. To satisfy the growing energy demand in ASEAN, huge energy-related infrastructure investment is necessary between now and 2050. This study estimates that about $500 billion–$550 billion will be necessary in the power generation sector, of which combined variable renewables (wind and solar) will require $68 billion–$168 billion from the BAU scenario to the APSs, respectively. More broadly, the IEA (2017) projected that $2.1 trillion will be required for oil, gas, coal, and power supply infrastructure in ASEAN. More than 60% of investment goes to the power sector, with transmission and distribution accounting for more than half of the total necessary investment. Globally, the Ministry of Finance of Japan (2019) estimated that the infrastructure investment gap is estimated to be $15 trillion from now until 2040. Asia alone will have a $4.6 trillion investment gap from now until 2040 (Ministry of Finance, Japan, 2019). the huge potential for energy infrastructure related investment will need to be guided by appropriate policies to promote quality infrastructure and resilience in ASEAN for growth and sustainability. Thus, ASEAN will need to prepare an array of policies suited to specific conditions to facilitate investment opportunities.

6. Conclusions and Policy Implications

The results of various scenarios have shown that ASEAN's current and future energy mix relies greatly on fossil fuels. The current share of fossil fuels is almost 80% in the primary energy supply and its future share is projected to be 87% under the BAU scenario and 78% under the APS. ASEAN's emissions will remain very high in all APS scenarios. To limit the temperature rise to 2° Celsius, emissions will need to fall to half by 2030 and reach net zero emissions by 2050 from 2010 levels. Thus, the clean use of fossil fuels through clean technologies and CCUS will be the only technological options to decarbonise emissions from fossil fuel use. In the energy transition, natural gas should be promoted as a transitional fuel in ASEAN, given the abundant supply from Australia. Renewables, energy efficiency, and green hydrogen[5] should be accelerated – along with the adoption of clean ecotechnologies – in the medium to long term in ASEAN's future energy system. Policies to manage ASEAN's energy transition need to be weighed against potentially higher energy costs, affordability, and energy security risks. Oil is the dominant energy source in the transport sector, while natural gas and coal are the dominant energy sources for power generation in ASEAN. The higher share of natural gas in ASEAN's power mix is a step in the right direction in promoting natural gas use in the energy transition towards a cleaner energy system.

In many ASEAN countries, coal use in power generation has been locked into the foreseeable future energy mix, as current and future coal-fired power generation generally involves 20- to 35-year power purchasing agreements with state-owned utilities to provide electricity. Thus, ignoring coal use in ASEAN means ignoring the reality and emissions of coal use. Considering the clean use of coal as part of ASEAN's energy transition is crucial to address the priorities of energy affordability and climate change. The deployment of CCT is urgent in the ASEAN region. Although ASEAN's energy targets have been set to include more renewables, ASEAN faces challenges in implementing such targets because renewables remain expensive in terms of the system integration cost to achieve high penetration in the grid system. Smart grids using the internet of things will provide

[5] Green hydrogen refers to the hydrogen production from renewable electricity.

a new green investment infrastructure which allows more penetration of renewables, but significant investment is required such as hard grids, internet of things technologies and applications, data management, and human resources.

A cleaner energy system in ASEAN relies on today's actions, policies, and investments to accelerate a higher share of renewables, the adoption of clean technologies and clean use of fossil fuels, and investment in climate-resilient energy quality infrastructure. The need for variable renewable investment in the power mix is estimated to be $118 billion in the APSs. Finally, willingness to pay is crucial if ASEAN is to leapfrog from its current energy system towards more efficient and clean technologies and a higher share of renewables in the energy mix.

Below are the key policy implications from the study:

- AMS will require assistance from developed countries to support the deployment of clean coal technologies, so that some developing countries in ASEAN will be able to afford clean coal technologies (e.g. USC or A-USC) to remove pollutants and increase the efficiency of power plants.
- The current climate narrative and policy approach of banning coal use should be reviewed to assist emerging Asia to afford CCTs, if alternative energy options are not available or feasible for emerging Asia in the medium term to meet energy demand. Treating CCTs as technology solutions in the energy transition will be a win–win solution for the world in terms of mitigating emissions and for Asia in sustaining energy accessibility and affordability.
- Emerging Asia will rely on whatever CCTs are available in the market at an affordable price. The up-front cost of such USC or A-USC technology is higher than that of supercritical (SC) and sub-critical (C) technology. Thus, it is necessary to lower such costs through policies such as attractive financing loan schemes for USC technologies, or a strong political institution to deliver public financing for CCTs to emerging Asia.
- A policy framework should clearly state the corporate social responsibilities of developed and developing nations, respectively, by highlighting the near- and long-term policy measures towards the coal industry and coal-fired power generation. As emissions in ASEAN are expected to rise until 2050, carbon recycling technologies will be necessary. In this regard, the world needs to

accelerate the research, development, and deployment of CCUS for commercialisation in the near future.

- There is a need to accelerate smart grid infrastructure development and investment, and energy cooperation from developed countries to share the experience of energy system integration, to achieve a higher share of renewables in the power system.
- ASEAN should promote natural gas use in the energy transition, as it creates only half the emissions that coal produces. Thus, investment in natural gas infrastructure will be crucial to increase natural gas use in ASEAN.
- ASEAN should accelerate the penetration of renewables, while increasing the adoption of clean technologies and the deployment of CCUS in the foreseeable future.
- ASEAN’s leaders should consider the gradual removal of blanket fossil fuel subsidies, but should replace them with subsidies targeted at vulnerable groups to help meet their basic energy needs and support their well-being.
- Other energy policy measures should consider the potential higher energy costs, energy affordability and accessibility, and energy security risks. Regular surveys to assess people’s willingness to pay for energy costs will be key in planning policy measures/reforms.

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Annex Table 1: Estimates of Primary Energy Supply and Percentage Changes from BAU to APSs, 2030

(Mtoe)

Item	2017	2030								
	Baseline	**BAU**	**APS**	**% change (BAU vs APS)**	**APS_RE**	**% change (BAU vs APS_RE)**	**APS_EI**	**% change (BAU vs APS_EI)**	**APS_EmT**	**% change (BAU vs APS_EmT)**
Coal	143	220	164	−25	195	−12	199	−10	118	−46
Oil	228	374	357	−5	366	−2	340	−9	314	−16
Natural gas	119	214	190	−11	209	−2	188	−12	172	−20
Nuclear	0	0	0	0	0	0	0	0	0	0
Hydro	16	24	24	0	25	7	23	−4	24	0
Geothermal	20	32	32	1	34	6	30	−5	32	2
Biomass	105	102	102	1	113	11	97	−5	97	−5
Solar, wind, ocean	1	6	12	90	12	81	6	−7	10	62
Biofuels	7	12	11	−7	18	48	10	−17	13	5
Electricity	−1	2	0	−108	2	19	0	−104	0	−106
Total	**639**	**986**	**893**	**−9**	**974**	**−1**	**893**	**−9**	**780**	**−21**

APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, BAU = business as usual, Mtoe = million tonnes of oil equivalent.
Source: Authors' calculations.

Annex Table 2: Estimates of Primary Energy Supply and Percentage Changes from BAU to APSs, 2050

(Mtoe)

Item	2017	2050								
	Baseline	**BAU**	**APS**	**% change (BAU vs APS)**	**APS_RE**	**% change (BAU vs APS_RE)**	**APS_EI**	**% change (BAU vs APS_EI)**	**APS_EmT**	**% change (BAU vs APS_EmT)**
Coal	143	409	251	−39	360	−12	335	−18	145	−65
Oil	228	721	602	−17	681	−6	586	−19	423	−41
Natural gas	119	450	342	−24	432	−4	366	−19	245	−46
Nuclear	0	0	6	557	0	0	0	0	7	718
Hydro	16	31	30	−3	35	16	30	−3	28	−8
Geothermal	20	63	74	17	101	61	51	−19	41	−35
Biomass	105	99	104	4	127	28	87	−13	91	−8
Solar, wind, ocean	1	14	25	80	24	71	12	−16	24	72
Biofuels	7	28	23	−20	50	76	21	−26	13	−56
Electricity	−1	7	6	−12	6	−10	6	−7	3	−59
Total	**639**	**1,823**	**1,461**	**−20**	**1,817**	**0**	**1,493**	**−18**	**1,018**	**−44**

APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, BAU = business as usual, Mtoe = million tonnes of oil equivalent.

Source: Author’s calculations.

Annex Table 3: Estimates of Final Energy Consumption and Percentage Changes from BAU to APSs, 2030

(Mtoe)

Item	2017	2030								
	Baseline	BAU	APS	% change (BAU vs APS)	APS_RE	% change (BAU vs APS_RE)	APS_EI	% change (BAU vs APS_EI)	APS_EmT	% change (BAU vs APS_EmT)
Industry	148	248	227	−8	241	−3	220	−11	199	−20
Transportation	129	231	201	−13	231	0	201	−13	184	−20
Others	141	190	177	−7	189	−1	176	−8	158	−17
Non-energy	62	80	80	0	66	−18	66	−18	66	−18
Total	**480**	**750**	**686**	**−9**	**727**	**−3**	**663**	**−12**	**607**	**−19**

APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, BAU = business as usual, Mtoe = million tonnes of oil equivalent.
Source: Authors' calculations.

Annex Table 4: Estimates of Final Energy Consumption and Percentage Changes from BAU to APSs, 2050

(Mtoe)

Item	2017	2050								
	Baseline	BAU	APS	% change (BAU vs APS)	APS_RE	% Change (BAU vs APS_RE)	APS_EI	% Change (BAU vs APS_EI)	APS_EmT	% Change (BAU vs APS_EmT)
Industry	148	453	386	−15	448	−1	381	−16	250	−45
Transportation	129	483	374	−23	486	1	376	−22	246	−49
Others	141	294	253	−14	294	0	253	−14	190	−36
Non-energy	62	126	126	0	109	−13	109	−13	109	−13
Total	**480**	**1356**	**1139**	**−16**	**1,337**	**−1**	**1,119**	**−17**	**794**	**−41**

APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, BAU = business as usual, Mtoe = million tonnes of oil equivalent.
Source: Authors' calculations.

Annex Table 5: Estimates of Power Generation Mix and Percentage Changes from BAU to APSs, 2030

(TWh)

Item	2017	2030								
	Baseline	**BAU**	**APS**	**% change (BAU vs APS)**	**APS_RE**	**% change (BAU vs APS_RE)**	**APS_EI**	**% change (BAU vs APS_EI)**	**APS_EmT**	**% change (BAU vs APS_EmT)**
Coal	381	608	449	−26	582	−4	552	−9	298	−51
Oil	26	23	21	−9	21	−8	22	−5	10	−57
Natural gas	414	743	669	−10	660	−11	645	−13	591	−20
Nuclear	0	0	0	0	0	0	0	0	0	0
Hydro	183	267	276	4	397	49	267	0	278	4
Geothermal	23	37	37	1	39	7	35	−5	38	2
Others	14	91	169	86	193	113	86	−5	201	122
Total	**1,041**	**1,768**	**1,622**	**−8**	**1,892**	**7**	**1,607**	**−9**	**1,416**	**−20**

APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, BAU = business as usual, TWh= terawatt-hour.
Source: Authors' calculations.

Annex Table 6: Estimates of Power Generation Mix and Percentage Changes from BAU to APSs, 2050

(TWh)

Item	**2017**	**2050**								
	Baseline	**BAU**	**APS**	**% change (BAU vs APS)**	**APS_RE**	**% change (BAU vs APS_RE)**	**APS_EI**	**% change (BAU vs APS_EI)**	**APS_EmT**	**% change (BAU vs APS_EmT)**
Coal	381	1,232	772	−37	1,054	−14	1,005	−18	398	−68
Oil	26	12	12	1	12	0	11	−3	12	0
Natural gas	414	1,582	1,303	−18	1,700	7	1,359	−14	919	−42
Nuclear	0	0	21	2,137	0	0	0	0	28	2,757
Hydro	183	356	344	−3	537	51	346	−3	326	−8
Geothermal	23	73	86	17	118	61	59	−19	47	−35
Others	14	185	356	93	406	120	167	−10	376	104
Total	**1,041**	**3,439**	**2,895**	**−16**	**3,827**	**11**	**2,948**	**−14**	**2,105**	**−39**

APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, BAU = business as usual, TWh = terawatt-hour.
Source: Authors' calculations.

Annex Table 7: Estimates of CO_2 Emissions and Percentage Changes from BAU to APSs, 2030

(Mt-C)

Item	2017	2030								
	Baseline	**BAU**	**APS**	**% change (BAU vs APS)**	**APS_RE**	**% change (BAU vs APS_RE)**	**APS_EI**	**% change (BAU vs APS_EI)**	**APS_EmT**	**% change (BAU vs APS_EmT**
Coal	147	227	144	−37	197	−13	197	−13	122	−46
Oil	138	249	147	−41	258	3	238	−5	202	−19
Natural gas	91	152	100	−34	148	−3	139	−9	105	−31
Total	**376**	**628**	**391**	**−38**	**603**	**−4**	**574**	**−9**	**429**	**−32**

APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, BAU = business as usual, Mt-C = million tonnes of carbon equivalent.

Source: Authors' calculations.

Annex Table 8: Estimates of CO_2 Emissions and Percentage Changes from BAU to APSs, 2050

(Mt-C)

Item	2017	2050								
	Baseline	**BAU**	**APS**	**% change (BAU vs APS)**	**APS_RE**	**% change (BAU vs APS_RE)**	**APS_EI**	**% change (BAU vs APS_EI)**	**APS_EmT**	**% change (BAU vs APS_EmT**
Coal	147	432	264	−39	360	−17	317	−27	151	−65
Oil	138	503	395	−21	507	1	437	−13	280	−44
Natural gas	91	281	216	−23	275	−2	244	−13	132	−53
Total	**376**	**1,217**	**876**	**−28**	**1,141**	**−6**	**998**	**−18**	**563**	**−54**

APS = alternative policy scenario, APS_EI = alternative policy scenario with energy intensity targets, APS_EmT = alternative policy scenario with emission reduction targets, APS_RE = alternative policy scenario with renewable targets, BAU = business as usual, Mt-C = million tonnes of carbon equivalent.

Source: Authors' calculations.

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