Decarbonizing Emissions in the Electricity Sector of the Mekong Subregion: Policy Implications

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Abstract The Mekong subregion faces tremendous challenges regarding the future energy landscape and how the energy transition will embrace a new architecture. This includes sound policies and technologies to ensure energy access, affordability, energy security, and energy sustainability. Fossil fuels (oil, coal, and natural gas) comprise almost 80% of the region's current energy mix. Moreover, the region will continue to rely on fossil fuels for economic growth in the foreseeable future. Thus, decarbonising emissions in the Mekong subregion is critically important to redirect the energy trajectory of fossil fuel–based energy system to low-carbon and green energy systems. This chapter discusses the energy landscape, including the rising electricity demand in the region, explores the potential of renewables in replacing fossil fuels in the electricity sector, and examines the possibility of carbon capture, utilisation, and storage for remaining emissions from coal and natural gas power generation. It also examines the power generation sector's market structure and policy challenges to embrace electricity market liberalisation in the region. Finally, the chapter will provide policy recommendations to stakeholders, such as electricity authorities and business players in this market.

Keywords Decarbonisation · Power mix · Renewables · And clean energy and technologies

JEL Codes Q59 · Q49 and Q29

1 Introduction

Common energy challenges link the Mekong subregion.[1] There are challenges in maintaining economic growth and ensuring energy security while curbing climate

[1] The Mekong subregion here refers to the Lower Mekong subregion consisted of Cambodia, Lao PDR, Myanmar, Thailand,, and Viet Nam.

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change and reducing air pollution. At the intersection of these challenges is the corresponding need to rapidly develop and deploy energy efficiency, low-emissions coal technology, and double the share of renewables in the energy mix towards more inclusive and sustainable growth. This is because the region's energy demand is expected to rise significantly over the next 30 years (Kimura and Han 2020). Such an increase brings both opportunities and challenges, including climate change which is a result of fossil fuels. Despite significant progress in recent decades in terms of energy poverty alleviation, countries such as Cambodia and Myanmar are still struggling to provide energy access to their rural populations.

The coronavirus disease (COVID-19) pandemic caused a global economic downturn. Countries in the Mekong subregion and the Association of Southeast Asia Nations (ASEAN) were no exception. Since the outbreak of the COVID-19 pandemic in early 2020, the travel restrictions imposed by countries have impacted the service sectors, such as tourism, and industries, especially the supply chain. In addition, the pandemic brought the world economy into recession: global growth contracted by −4.9% in 2020, and all ASEAN countries experienced negative growth, except Viet Nam (Table 1) (WEO 2020). As the result, global carbon dioxide (CO_2) emissions were estimated to fall by 8% in 2020 compared to 2019 levels (Han 2020).

However, as governments begin lifting restrictions and business activities resume, so will the demand for energy. Economic recovery could see carbon dioxide (CO_2) emission levels bounce back very quickly (2 Institute 2020). The post-COVID-19 economic recovery will drive increased energy demand, which emphasises the need to find appropriate energy policy and strategy to permanently lower emissions as part of efforts to contribute to the Paris Agreement on climate change to limit the rising global temperature to lower than 1.5 °C by 2050.

Given the high share of fossil fuels (almost 80% share of oil, coal, and natural gas) in the Mekong subregion's energy mix in 2017, decarbonising the energy system will require efforts and commitment, such as policy reform and energy infrastructure

Table 1 Economic growth rate of Mekong Subregion and ASEAN countries

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Brunei	−2.9	1.4	2.4	2.7	−1.4	5.6	4.4	2.8	2.4	2.2
Cambodia	7.0	7.2	7.5	6.7	−3.9	5.6	6.2	6.2	6.2	5.7
Indonesia	5.7	4.5	−1.1	5.7	−4.8	5.5	4.7	4.0	3.8	3.8
Lao PDR	7.5	5.3	4.3	3.0	−9.2	−2.5	3.7	4.1	4.1	4.3
Malaysia	−1.7	2.1	11.7	1.6	−7.0	10.3	6.7	6.4	5.3	4.9
Myanmar	−5.1	−3.2	3.2	−3.2	−2.9	1.7	2.5	2.7	2.7	2.8
Philippines	2.7	0.8	1.8	7.8	−4.6	5.3	5.6	6.1	6.0	6.1
Singapore	2.7	4.4	5.9	−0.4	−7.5	7.2	3.4	3.1	3.0	2.9
Thailand	0.4	8.2	9.4	6.5	−5.8	4.5	5.8	5.3	5.0	4.2
Viet Nam	4.6	5.3	5.7	6.1	0.8	4.9	5.8	5.4	5.1	4.8

Source Data taken from database of WEO (2020) investment towards clean technologies, energy efficiencies, and renewable energy. Renewables such as solar and wind have contributed negligent amounts (2.4% in 2020) to the power mix (Han et al. 2021). Of course, reforms in the energy sector are needed, especially in the electricity market, to have more open competition in all sections of the electricity market, such as generation, transmission, and distribution. Further reform in rules and procedures will be needed to allow more advanced and competitive technologies to enter the market share of the energy mix rather than using old rules and procedures to favour traditional fuel. The future electricity market needs to move from the hybrid model 'single buyer' to full market competition, with an independent power regulator and regional institutional system operator to facilitate the electricity market in the wholesale and retail markets and encourage more market players to join. This way, electricity reform will attract foreign investment to modernise the electricity infrastructure, including more efficient power systems, and gradually allow inefficient power generation and technologies to phase out. The quality energy infrastructure needs to be promoted and adopted in the region to ensure inclusive growth to bring harmony amongst people, development, and environmental sustainability.

The pursuit of net-zero emission is starting. It is particularly challenging for many countries highly dependent on fossil fuels, especially for many developing countries worldwide. In ASEAN and East Asia, Japan and South Korea have joined the pledge for net-zero emissions by 2050, while China aims to achieve net-zero emissions by 2060. Singapore has also announced its ambitious plan to go net-zero emissions beyond 2050. Although many ASEAN countries have yet to set any specific target for net-zero emissions, countries are working hard to redesign their policy to a more sustainable and cleaner energy system (Nishimura 2021).

Going for a green and clean energy system will rely on clean technologies, such as carbon capture, utilisation, and storage (CCUS) and the deployment of renewable energy resources. We know that ASEAN is rich in solar photovoltaic (PV) resources. However, only a few countries, such as Philippines, Indonesia, and Viet Nam have offshore wind resources. On the other hand, Continental Southeast Asia, known as the Mekong subregion, is rich in hydropower resources. Thus, the high penetration of solar photovoltaic (PV) and wind in ASEAN could be facilitated by the future power connectivity and trade within the whole ASEAN. If the ASEAN electricity market gradually moves up to multilateral/electricity market, the hydropower resources from the Mekong subregion could play a significant role as the baseload power. It complements the high penetration of solar and wind energy very well (Han 2021).

However, the high penetration of variable renewable energy such as wind and solar will require a large capacity of electrical discharge 'battery storage' to back up the power shortage during the worse and extreme days of less sunshine and less wind. Since the large capacity of battery storage calls for huge investment costs, it is pragmatic to use thermal power plants for backup. In this case, CCUS is indispensable in the quest for decarbonised energy system (Han et al. 2020). While hydrogen is another crucial technology for decarbonisation, when it is produced from fossil fuels, CCUS is also needed to neutralise CO_2 emissions. Towards carbon neutrality, the International Energy Agency (IEA) estimated that almost half of the emission reduction must come from carbon sink technologies such as CCUS (IEA 2020). Thus, CCUS commercialisation will be central to the success of deep decarbonisation. This is particularly the case for the ASEAN region, including the Mekong subregion with strong presence of fossil fuels now and in the future.

The paper discusses the energy landscape of the Mekong subregion, including the rising electricity demand and the potential of renewables to replace fossil fuels in the electricity sector. The paper also examines the possibility of CCUS deployment for the remaining emissions from coal and natural gas power generation. The chapter also examines the challenges of market structure and policy in the power generation sector in moving forward to embrace electricity market liberalisation in the region. Finally, it provides policy recommendations to stakeholders, such as electricity authorities and business players in this market.

2 Energy Landscape and the Rising Electricity Demand in the Mekong Subregion

At the outset, this section employed the energy outlook and saving potential database of the Economic Research Institute for ASEAN and East Asia (ERIA). Experts from ASEAN and East Asia provided regular data inputs to produce regular energy outlook reports. The author of this paper is also the co-editor of the *Energy Outlook and Saving Potential for East Asia*. Thus, he accessed the database and extracted data for the energy landscape of the Mekong subregion. This section provides a view of the energy landscape, such as the energy supply and demand situation, including the power generation of the Mekong subregion.

The total primary energy supply (TPES) in the Mekong subregion (Cambodia, the Lao PDR, Myanmar, Thailand, and Viet Nam) is projected to increase by 189% in the business-as-usual scenario (BAU),[2] and by 121% in the alternative policy scenario (APS)[3] from 2017 to 2050. It will increase from 234 million tonnes of oil equivalent (Mtoe) in 2017 to 675 Mtoe in BAU, and 516 Mtoe in the APS by 2050. The Mekong subregion is heavily dependent on fossil fuels (oil, coal, and gas). Based on the baseline data in 2017, the fossil fuel share in the energy supply is around 75% of the total in the region. The region will see a growing dependence on fossil fuels in the future. In this regard, the study results showed that by 2050, the share of fossil fuels in the energy supply will be about 88% in BAU and 81% in the APS. In actual amounts, the combined coal, oil, and gas in the energy supply are expected to increase from 175 Mtoe in 2017 to 595 Mtoe in BAU and 420 Mtoe in the APS in 2050. Oil

[2] The business-as-usual scenario (BAU) was developed for each East Asia Summit country, outlining future sectoral and economy-wide energy consumption, assuming no significant changes to government policies.

[3] The alternative policy scenario (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.

is the dominant energy source in the energy supply, followed by natural gas and coal (Fig. 1). Oil is expected to increase from 74 Mtoe in 2017 to 255 Mtoe for BAU and 197 Mtoe for the APS in 2050. Natural gas is expected to increase from 49.3 Mtoe in 2017 to 184.3 Mtoe for BAU and 133.6 Mtoe for the APS in 2050. Coal will increase from 51.6 Mtoe to 155.8 Mtoe for BAU and 89.3 Mtoe for the APS in 2050. Other sectors, including biomass, wind, solar, and electricity, will increase from 58.8 Mtoe in 2017 to 80.0 Mtoe for BAU and 96.5 Mtoe for the APS in 2050.

The difference between BAU and the APS is the energy-saving potential in the TPES. Coal will see the largest energy savings, with a potential of 42.7%, followed by 27.5% for natural gas and 22.7% for oil. These large energy savings are expected from implementing energy efficiencies, with improved efficiency in thermal power plants and energy efficiency in end-use sectors such as transportation, industry, commercial, and residential. The Mekong subregion is expected to see an increase in renewables of about 20.6% in the energy supply mix by 2050 (Fig. 1).

Industry accounts for the largest share of the total final energy consumption (TFEC), followed by transportation and other commercial and residential sectors (Fig. 2). Energy consumption in the industry sector is expected to increase from 68 Mtoe in 2017 to 217 Mtoe for BAU and 184 Mtoe for the APS by 2050. Energy consumption in the transport sector is predicted to increase from 48 Mtoe in 2017 to 160 Mtoe for BAU and 104 Mtoe for the APS by 2050. For other sectors, including commercial and residential, energy consumption is expected to increase from 46 Mtoe in 2017 to 105 Mtoe for BAU and 89 Mtoe for the APS by 2050. Non-energy (naphtha) is also used in the TFEC, especially for the refinery and petrochemical industries. Its use will remain the same for BAU and the APS in 2050.

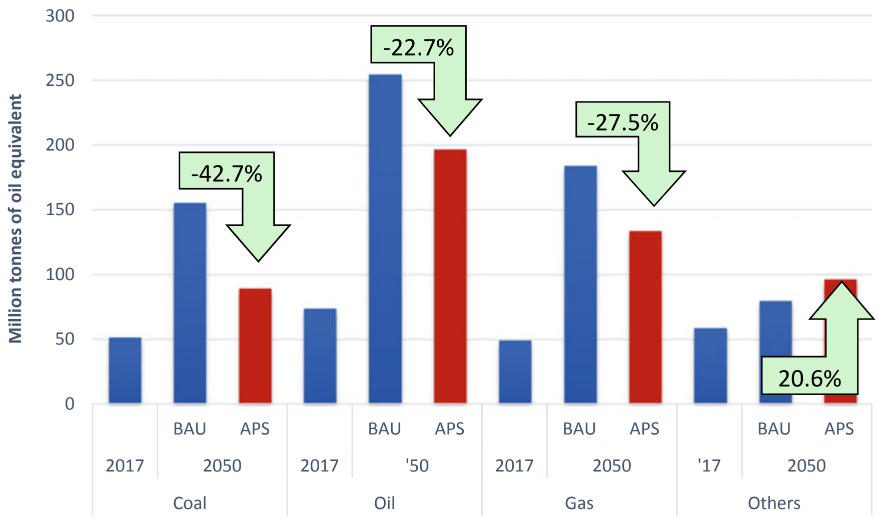

Fig. 1 TPES, by Energy Source, BAU versus APS. APS = alternative policy scenario, BAU = business-as-usual scenario, TPES = total primary energy supply. *Source* Author’s calculations

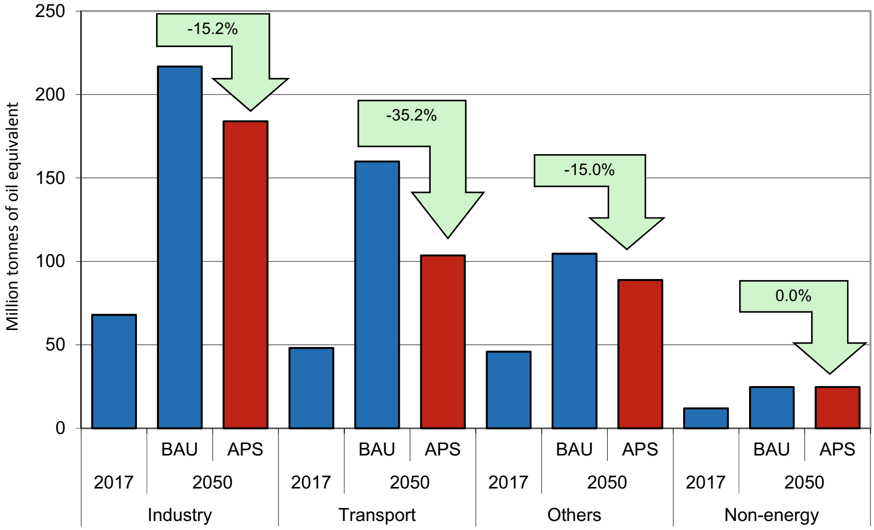

Fig. 2 TFEC, by Sector, BAU vs APS. APS = alternative policy scenario, BAU = business-as-usual scenario, TFEC = total final energy consumption. *Source* Author's calculations

Energy saving is expected to be highest for the transportation sector at 35.2%, 15.2% for the industry sector, and 15.0% for the commercial and residential sectors (Fig. 2). The reduction in energy consumption in the final energy sector will derive from fuel efficiencies in the transportation, industry, commercial, and residential sectors (e.g., the introduction of more efficient heat and power, a shift to electric vehicles, hybrid and fuel cell vehicles, more efficient electric appliances, and energy-saving buildings).

The natural gas is the dominant fuel source in power generation, followed by coal and hydropower (Fig. 3). Natural gas is expected to increase from 170.4 megawatt-hours (MWh) in 2017 to 798.7 MWh in 2050 in BAU and 690.3 MWh in the APS by 2050. Electricity from coal-fired power generation will increase from 116 MWh in 2017 to 374 MWh in BAU and 150 MWh in the APS by 2050. Electricity from hydropower is expected to increase from 133 MWh in 2017 to 252 MWh in BAU and 245 MWh in the APS by 2050.

Electricity from 'others' (including biomass, wind, and solar) will increase from 6.2 MWh in 2017 to 87.2 MWh in BAU and 172.4 MWh in the APS by 2050. Significant energy savings are expected in coal-fired power generation (59.7% savings, a reduction from BAU to the APS), followed by the gas combined cycle (13.6%). Energy savings in power generation are expected due to the introduction of high thermal efficiency. Electricity from renewables such as biomass, wind, and solar is expected to increase sharply by 97.7% due to upscaling of renewables in the power mix in the APS scenario than with BAU.

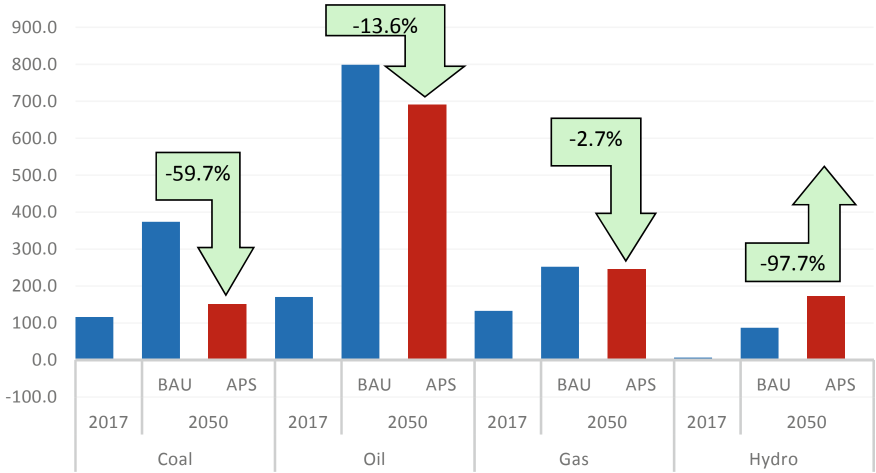

Fig. 3 Total Power Generation (TFEC), by Energy Source, BAU vs APS. APS = alternative policy scenario, BAU = business-as-usual scenario, TFEC = total final energy consumption. *Source* Author's calculations

3 Decarbonising the Electricity Sector in the Mekong Subregion

The region will continue to rely on fossil fuel in the foreseeable future. This is mainly because of the high combined share of fossil fuels in the power generation mix of the Mekong subregion, at 67% in 2017 and 78% in BAU by 2050 (Fig. 4). The decarbonisation scenario ($DeCO_2$) assumes a 30% reduction of coal, oil, and gas

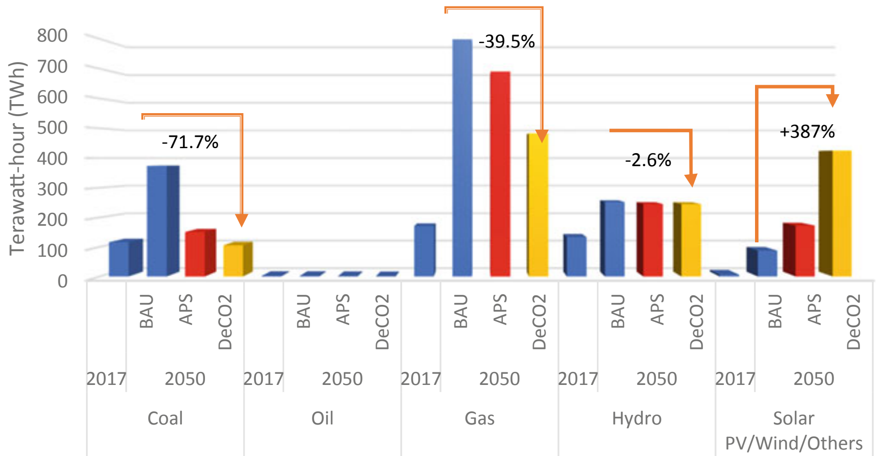

Fig. 4 Decarbonisation scenarios ($DeCO_2$) in the electricity sector. *Source* Author's calculations

further from the APS by 2050. At the same time, the reduction of power generation from fossil fuels is replaced by increasing renewables such as solar PV, wind, and biomass. Large fossil fuel power generation is expected to reduce substantially from BAU to $DeCO_2$. In this case, coal-fired power generation output will be reduced by almost 72% from BAU to $DeCO_2$; gas-fired power generation will be reduced by almost 40% from BAU to $DeCO_2$. In comparison, renewables are expected to increase by 387% from BAU to $DeCO_2$ (Fig. 4).

CO_2 emissions rose from 42 million tonnes of carbon equivalent (Mt-C) in 1990 to 127 Mt-C in 2017. CO_2 emissions are expected to rise to 457 Mt-C in BAU and 318 Mt-C in the APS by 2050. However, emissions will drop to 140 Mt-C in $DeCO_2$. It is a large reduction In percentage, about 69.2% emission reduction from BAU to $DeCO_2$ (Fig. 5). However, such a large emission reduction can only happen when renewables' acceleration can be realised by 2050.

Thus, $DeCO_2$ is considered in the high share of renewables, particularly solar PV and wind energy in the power generation mix. All Mekong subregion countries are rich in solar PV, while wind energy potential is scarce in the region, except for Viet Nam and some parts of Thailand (Global Solar Atlas 2021). Thus, decarbonising the electricity sector in the Mekong Subregion will greatly rely on the increasing share of solar PV and wind. Hydropower does not seem to be an option as the resources will reach their potential limitation. Furthermore, some of the Mekong mainstream hydropower may not be suitable from the viewpoint of sustainability. Thus, solar PV and wind are the resources that can be utilised, especially abundant solar resources, in

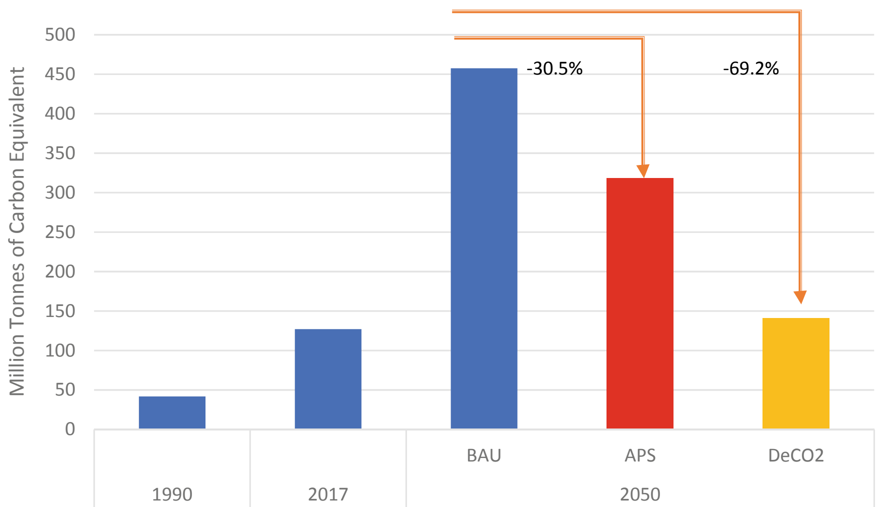

Fig. 5 CO_2 Emissions in the Mekong Subregion, BAU versus APS versus $DeCO_2$. APS = alternative policy scenario, BAU = business-as-usual scenario, CO_2 = carbon dioxide, Mt-C = million tonnes of carbon equivalent. *Note* The CO_2 emission reduction calculation method is the Greenhouse Gas Equivalencies, using an emission factor of 7.03×10^{-4} metric tonnes CO_2/kWh (EPA, US Environmental Protection Agency 2019). *Source* Author's calculations

the Mekong region. The remaining energy sources will come from fossil fuels, but the clean use of fossil fuels through clean technology deployment must be considered. In this regard, CCUS must deal with the remaining emissions from fossil fuels.

According to the solar PV potential, these resources are not constrained or limited in replacing fossil fuels. The main reason is the cost of doing so and how practically the grid can absorb such high penetration of variable renewable energy (VRE) such as solar and wind. Technically, VRE power production output varies within a few seconds depending on wind or sunshine. However, the risk of variable energy output can be minimised if the power system is largely integrated within the country and the region. Aggregating output from different locations from solar and wind energy has a smoothing effect on net variability (NREL 2020).

The Mekong subregion grid is progressing slowly. The integrated Mekong subregion power market might be far off for several reasons, such as regulatory and technical harmonisation issues within the region's power grids and utilities. Thanks to advanced research and technologies for battery storage (lithium-ion batteries) for surplus electricity produced from wind and solar energy. However, advanced battery storage remains costly. Further, the renewable hydrogen produced from electrolysis using surplus electricity from wind and solar has many advantages. It can be stored as liquid gas, suitable for numerous uses such as backup power generation, or as a liquid fuel that is easy to transport for other uses. Countries in the Mekong region could produce wind, solar, hydropower, or geothermal electricity and use surplus electricity to produce green hydrogen or store it as battery storage.

3.1 Low-Cost Renewables with Hydrogen Are the Game Changer

The fast drop in the cost of renewables can make DeCO_2 a reality. The levelized cost of electricity (LCOE) is expected to fall below US$4 cents/KWh in 2021 for solar PV and onshore wind (Fig. 6) (IRENA 2020). This low cost can be an enabler to producing hydrogen or largely deploying solar PV and wind.

Hydrogen is a potential game changer for decarbonising emissions, especially in sectors where they are hard to abate, such as cement and steel. Scalable resources from wind and solar energy and other renewables can be fully developed by widely adopting the hydrogen solution. The more electricity produced from wind and solar energy, the higher the penetration by grid renewables. At the same time, surplus electricity during low demand hours can be used to produce hydrogen. The more power generated from wind and solar energy and other renewables, the greater the possibility of increasing the efficiency of electrolysis to produce hydrogen. On-site hydrogen production from wind and solar farms will solve the issue of curtailed wind and solar electricity. To increase electrolysis efficiency and allow further penetration by renewables of grids, a hybrid energy system including hydropower, geothermal, or nuclear plants, for example, would be the perfect energy choice. Hydrogen is a

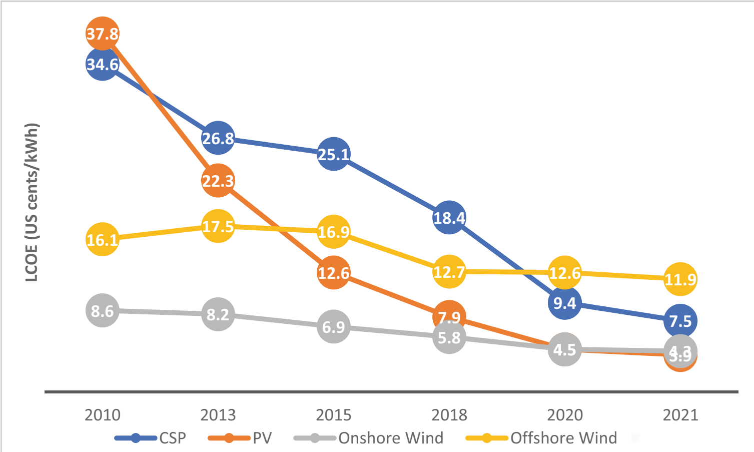

Fig. 6 Falling costs of renewables. CSP = concentrated solar power, kWh = kilowatt-hour, LCOE = levelized cost of electricity, PV = photovoltaic. *Source* IRENA (2020)

clean energy carrier that can be stored and transported for use in hydrogen vehicles, synthetic fuels, upgrading of oil and/or biomass, ammonia and/or fertiliser production, metal refining, heating, and other end uses. Thus, hydrogen development is an ideal pathway to a sustainable clean energy system and enables scalable VRE, such as solar and wind energy.

3.2 The Need to Strengthen Environmental Standards for Power Generation in the Mekong Subregion

Mitsuru et al. (2017) reported Mekong subregion countries have relatively high allowable emissions in terms of sulphur oxides (SOx), nitrogen oxides (NOx), and particulate matter (PM) (Fig. 7). This means that countries in the subregion have lower emissions standards than advanced countries such as Germany, the Republic of Korea, and Japan, where clean coal technology is mandatory.

Major harmful air pollutants, such as SOx, NOx, and PM, come from fossil fuel and biomass power plants, which must be carefully regulated. Short-term exposure to sulphur dioxide can harm the human respiratory system and make breathing difficult.

Thus, the region’s leaders may need to consider promoting and effectively enforcing clean technologies, higher standards, or stringent environmental regulations for coal-fired power plants. This may push investors to select more advanced and clean technologies.

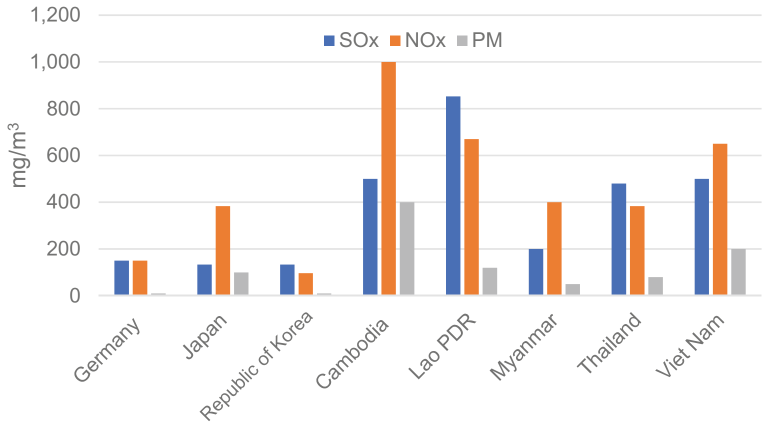

Fig. 7 Emissions standards for newly constructed CPPs in selected countries. (SOx, NOx, and PM). CPP = coal-fired power plant, Lao PDR = Lao People's Democratic Republic, mg/m^3 = milligram per cubic metre, SOx = sulphur oxides, NOx = nitrogen oxides, PM = particulate matter. *Source* Mitsuru et al. (2017)

3.3 Moving Towards ASEAN Power Connectivity

The Heads of ASEAN Power Utilities/Authorities (HAPUA) plays a significant role in pursuing the future integration of the ASEAN Power Grid (APG) (HAPUA 2019). HAPUA's mission is to support the ASEAN Economic Community through ASEAN energy market integration by succeeding in implementing the APG. Amongst the cross-border interconnections in ASEAN member states (AMSs), the Mekong subregion's interconnection has already existed. These interconnections mainly consist of medium/low voltage (115 kV or less) transmission lines and a few high-voltage transmission lines (500 kV, 230/220 kV). An electricity power trade has been carried out amongst Greater Mekong Subregion countries. However, it is bilateral or based on a power purchase agreement (PPA) that independent power producers sell electricity via dedicated transmission lines to power utilities. The cross-border interconnection of a 500 kV transmission line is only installed to dedicated transmission lines for the PPA. Therefore, electricity power trade in ASEAN has been limited.

The AMSs have long recognised the potential benefits of the APG; however, this benefit can only be realised when they establish the multilateral power trade in the ASEAN region. Generally, utilising the value of the difference is one of the key reasons for regional integration and cooperation, positively affecting the security of supply and, hence, grid stability. In addition, the economic benefits of having complementary production are one of the main drivers and reasons for building interconnections. The ASEAN Plan of Action for Energy Cooperation 2016–2025 explains that an interconnected APG brings multiple benefits. (ERIA 2015). Multilateral power trade aims to optimise resources on a regional, instead of a national, basis to meet the electricity demand in the region as a whole at the least possible cost. Multilateral power trade results in the following key potential benefits, amongst others:

(1) It enables more efficient use of the region's energy resources, leading to lower overall production costs in the APG since optimal investments can be made on the regional scale instead of suboptimal solutions separately in each country.
(2) It helps the utilities in the region balance their excess supply and demand, improves access to energy services, and reduces the costs of developing energy infrastructure.
(3) It accelerates the development and integration of renewable power generation capacity into the regional grid.
(4) It reduces the need for investment in power reserves to meet peak demand, lowering operational costs while achieving a more reliable supply and reducing system losses.
(5) It attracts additional investment in the region's interconnection by providing a price signal as a key catalyst for investors' financial returns.

To trigger the multilateral power trade in ASEAN, the AMSs have completed a pilot project of 100 MW phase I called the Lao PDR–Thailand–Malaysia –Singapore Power Integration Project (LTM-PIP) as the first multilateral power trade in ASEAN. Now phase II of the project aims to increase multilateral energy trade from 100 to 300 MW and commence work to include Singapore in the Lao PDR–Thailand–Malaysia–Singapore Power Integration Project (LTMS-PIP) in 2020 (HAPAU 2019).

Developing a common wheeling methodology will be necessary to establish multilateral power trading in the region. The LTMS-PIP wheeling methodology could be an appropriate start. The LTMS-PIP wheeling charge is based on the following elements: (i) the distance of the trade (megawatts per mile); (ii) a loss charge (charged per megawatt-hour); (iii) a balancing charge (per megawatt-hour); and (iv) a fixed administrative charge. The LTMS partner countries will need to share additional details on how each component is calculated to generalise this methodology for ASEAN. However, it should be emphasised that this can be done without sharing the actual wheeling charge applied to the LTMS-PIP trade, should this information be considered too sensitive to share publicly.

The underlying process used to develop this project is also very relevant to the ASEAN-wide discussion. In particular, work on the project was divided across four working groups, which looked at (i) tax and tariff structure, (ii) commercial arrangement, (iii) technical viability study, and (iv) regulatory and legal arrangements, each of which was led by a different country. There are two key lessons from this arrangement. First, dividing work across the participating countries is a good way of giving everyone a stake in, and a sense of ownership over, the underlying process and, therefore, the overall project. Second, a particular AMS may be actively involved in the development process even if it does not participate in the trading arrangement itself. This is an important lesson for ASEAN as a whole, as it is sure to be the case that some AMSs will participate in multilateral power trade early on (IEA 2020).

Moving forward to the multilateral power market within ASEAN or the Mekong subregion is still a long way. One reason for the slow progress is the many types of power sector structures and markets throughout ASEAN, creating problems and barriers on all levels of collaboration. These challenges remain in setting up the following: (i) a regional regulators group/regional regulatory body to harmonise regulations and standards relevant to grid interconnection, (ii) a regional operators group or regional system operator to synchronise actions in balancing the grid and the cross-border power exchange systems, and (iii) a regional system planners' group to coordinate and optimise the future investment plan of power stations and the grid.

HAPUA, the ASEAN Centre for Energy, ERIA, and the Asian Development Bank conducted several studies to solve these issues. The findings suggest harmonising the legal and regulatory frameworks and creating technical standards and codes relating to planning, design, system operation, and maintenance. In addition, ERIA conducted two studies to support ASEAN's future power market. The first was the 'Study on the Formation of the ASEAN Power Grid Transmission System Operators (ATSO) Institution'. Its two layers of objectives were (i) to establish the roles, structures, operational guidelines, and processes of the ATSO institution; and (ii) to provide a detailed implementation plan for the creation and operation of ATSO. This study overviewed the international case examples used to create ATSO, the ASEAN Power Pool (APP) guidelines, and the APP Implementation Plan and Roadmap (ERIA 2018a). The second was the 'Study on the Formation of the ASEAN Power Grid Generation and Transmission System Planning (AGTP) Institution'. It aimed to propose applicable procedures, structures, roles, and mechanisms to establish and maintain the AGTP. ATSO and the AGTP institutions, once achieved, would symbolise regulatory connectivity in ASEAN. This study provided case examples in this field in Japan, Europe, and the Southern African region to refer to and learn AGTP guidelines and the AGTP implementation plan (ERIA 2018b).

These two studies aimed to help the AMSs achieve consensus on the principles, building blocks, and framework of an integrated regional electricity market. The output from the two studies concluded that the functions of the AGTP and ATSO should be placed in the same organisation to secure a close relationship between planning and power system operations. After discussions during the AGTP and ATSO studies workshops, the ASEAN Power Grid Consultative Committee (APGCC) and the AMSs agreed to merge the functions of the AGTP and ATSO into one organisation, named the ASEAN Power Pool (APP). APP's primary role will be to act as a coordinating body with the AMS transmission system operator, focusing on harmonising operational standards across ASEAN to achieve a more efficient operation of the future APG. More efficient operations are anticipated to come from better coordination and alignment of the system operation and generation within the region. The APP is expected to be a key institution to enable multilateral trading of electricity amongst the AMSs while maintaining the balance, stability, and reliability of the interconnected power grids across borders. In addition, coordinating APG system planning, and grid developments will be greatly important in making the APG more efficient and better coordinated.

The APP will resemble a forum where operational, technical, and multilateral trading topics can be discussed and agreed. It will also have an essential information-sharing role for the region. The suggested responsibilities of the APP will be to lead and coordinate the development of the regional market, establish, and own the APG network codes and guidelines, and produce a regional system planning and development plan that will be continuously revised going forward. Code development by the APP and overall activity shall focus on interconnections, and how these will be utilised best. The APP shall not have an operational role within the different AMS national transmission grids. Instead, it is proposed to be responsible for the APG system operational coordination. This responsibility will be achieved through the 'Control Block Coordination Centre'. The point is that there should be only one coordination centre in ASEAN.

4 Conclusion

The Mekong subregion faces mounting challenges matching its increasing electricity demand with a sustainable energy supply. This is because the regional reliance on fossil fuel consumption is projected to last until 2050. The transition to a lower-carbon electricity sector will require the region to develop and deploy renewables, greener energy sources, and clean use of fossil fuels through innovative technology such as high-efficiency, low emissions technologies, and the deployment of CCUS. Coal- and natural gas–fired power generation patterns in the region reflect the rising demand for electricity to power and steer economic growth. Hence, building low-efficiency coal-fired power plants is an obvious choice for power-hungry emerging Mekong subregion due to lower capital costs. However, such plants cause more environmental harm and health issues due to air pollution, CO_2, and other GHG emissions. Widespread coal power plant construction could also point to the low environmental standards for coal-fired power generation in the Mekong subregion. The role of natural gas in the energy transition cannot be overlooked. This is because it can be used as a bridging fuel between high emissions fuels, such as coal and oil, to cleaner energy systems in which renewables and clean fuels take the major share in the energy supply mix.

In the current situation, hydropower accounts for quite a large share of the energy mix in the Mekong subregion. However, as energy demand is expected to increase further, hydropower sources will be fully utilised. Thus, the share of renewables, such as wind, solar, and biomass, will play a critical role in $DeCO_2$ for the future clean electricity system in the region. The lower cost of these renewables will make it possible for a higher share of wind and solar in the energy mix. Since electricity from wind and solar sources is variable and intermittent, there is a need to invest in grid infrastructure with smart grids, using the internet of things and other technology to predict electricity production. This will ensure proper system integration in which battery storage and hydrogen fuels play a critical role in the backup system. The Mekong subregion may benefit greatly from developing the full potential of renewables and hydrogen production because of its large solar, wind, and hydropower potential. Thus, electricity from wind and solar, plus other unused electricity during low-demand hours, should be converted to be stored in a large battery or to hydrogen as stored energy. Thus, decarbonisation electricity in the Mekong subregion will rely on the high share of renewables, especially solar PV, wind, hydropower, and biomass.

The future institution of the APP and the Mekong subregion needs to be established and operated. The power pool, once up for running with the proper institutions guided by regional electricity market rules and procedures, can hugely benefit the region in terms of (i) avoided cost of building new generations, (ii) creation of more efficient use of the region's energy resources, (iii) helping the utilities in the region balance their excess supply and demand, (iv) improving access to energy services, (v) reducing the costs of developing energy infrastructure, (vi) accelerating the development and integration of renewable power generation capacity into the regional grid, (vii) reducing the need for investment in power reserves to meet peak demand, and (viii) attracting additional investment in the region's interconnection by providing a price signal as a key catalyst to investors for their financial returns.

However, reforms will be needed in the electricity sector, especially the deregulation of national and own rules and procedures to join the regional power pool's rules and procedures. Further, the unbundling of ownerships in the electricity market segments and the non-discriminatory third-party access for transmission and distribution networks, and the gradual removal of subsidies in fossil fuel–based power generation are to ensure the preconditions for market competition by bringing a level playing field to new technologies and renewables into the energy mix. Other necessary policies to attract foreign investment into renewables and clean technologies included fiscal policy incentives of tax holidays, reducing market barriers and regulatory burden, other policies to reduce upfront cost investments, such as rebated payment system through government subsidies and government guarantee to make the investment become feasible and low risk.

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