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Key Points:

- Power plants under development in Southeast Asia will double the region's fossil fuel capacity and its committed power sector CO₂ emissions
- Power supply projections from 2020 to 2030 for fossil fuel plants in Indonesia and the Philippines greatly exceed projected demand
- Coal and gas plants in Indonesia and the Philippines will likely become stranded assets and/or will crowd out renewable deployment

Supporting Information:

Supporting Information may be found in the online version of this article.

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The Expanding Coal Power Fleet in Southeast Asia: Implications for Future CO₂ Emissions and Electricity Generation

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Abstract Coal combustion for power generation made up 30% of global CO₂ emissions in 2018. To achieve the goal of the Paris Agreement to keep global average temperatures below 2°C, power generation must be decarbonized globally by mid-century. This requires a rapid phase-out of coal-fired power generation. However, global coal power expansion continues, mostly in developing countries where electricity demand continues to increase. Since the early 2010s, Southeast Asia's coal power capacity expansion has been among the fastest in the world, following China and India, but its implications for the global climate and regional energy transition remain understudied. Here we examine Southeast Asia's power generation pipeline as of mid-2020 and evaluate its implications for the region's CO₂ emissions over the plant lifetime as well as projected electricity generation between 2020-2030 in Indonesia, Vietnam, and the Philippines. We find that power plants under construction and planned in Southeast Asia as of 2020 will more than double the region's fossil fuel power generation capacity. If all fossil fuel plants under development are built, Southeast Asia's power sector CO₂ emissions will increase by 72% from 2020 to 2030 and long-term committed emissions will double. Moreover, in Indonesia, Vietnam, and the Philippines, projected electricity generation from fossil fuel plants under development, combined with generation from renewable capacity targets and existing power capacity, will exceed future national electricity demand. As a result, fossil fuel plants will likely be underutilized and/or become stranded assets while also potentially crowding out renewable energy deployment.

Plain Language Summary Fossil fuel power plants lock in CO₂ emissions for their multi decades-long lifetime and interfere with global decarbonization efforts to address climate change. To avoid catastrophic climate change, the world must phase out fossil fuel power plants and transition to a low carbon energy system rapidly. However, Southeast Asia's fossil fuel generation capacity continues to expand. To understand the implications of this fossil fuel fleet expansion for the global climate and regional electricity supply, we analyze the long-term committed CO₂ emissions from operating, under-construction, and planned fossil fuel plants in the region as well as projected electricity generation in three countries: Indonesia, Vietnam, and the Philippines. We find that the expanding fossil fuel power fleet in Southeast Asia will double the region's power sector CO₂ emissions. Furthermore, it will likely cause an "oversupply" of electricity, which will either result in financial losses and/or will crowd out renewable energy deployment. Power sector planning in Southeast Asia must recognize these risks and ensure a timely transition to low carbon energy.

1. Introduction

Greenhouse gas (GHG) emissions from fossil fuel combustion are the primary cause of global temperature increases since pre-industrial time. Coal combustion for electricity generation accounted for 30% of global CO₂ emissions in 2018 (International Energy Agency, 2019a, 2020a). To reach the Paris Agreement goal of limiting average global warming to well below 2°C and preferably under 1.5°C above pre-industrial levels, a rapid phase-out of coal-fired power generation is crucial (Fofrich et al., 2020; Rogelj et al., 2018). Replacing coal-fired power generation with low carbon technologies can dramatically reduce CO₂ emissions. Furthermore, decarbonizing electricity generation is a key mechanism to facilitate economy-wide decarbonization as buildings, transport and industry electrify (Edenhofer et al., 2014). However, global coal power fleet expansion is continuing, with the most capacity growth occurring in developing countries, where electricity demand is rapidly increasing. Specifically, Southeast Asia is poised for the fastest coal power capacity growth in the world following China and India.

An ample regional supply of coal, especially in Indonesia, and relatively low costs have led to coal having a prominent role in Southeast Asia's power generation sector. Rapidly decreasing costs of renewable technologies globally have made wind and solar technologies competitive with coal power in many regions of the world (LAZARD, 2020). However, levelized costs of electricity (LCOE) for wind and solar power are still higher than coal power in Southeast Asia (Zissler, 2019), as costs of locally produced coal resources are lower than international prices and coal power has long been subsidized by the governments (IRENA, 2018; Minh Do & Sharma, 2011). From 2000 to 2018, the share of Southeast Asia's power generation from coal increased steadily from around 20% to over 40% (International Energy Agency, 2019b). As of 2018, Southeast Asia was one of the few regions in the world with an expanding coal power fleet. As a result of the expanding power generation sector fueled by fossil fuels, CO₂ emissions from Southeast Asia increased from 1 Gt in 2010 to around 1.4 Gt in 2018. When most countries in the world slow their fossil fuel power generation growth, Southeast Asia is projected by the International Energy Agency (IEA) to continue to increase its fossil fuel consumption until 2040 based on current policies. Under the Stated Policies Scenario by IEA, Southeast Asia's CO₂ emissions will further increase by 65% from 2018 to 2.4 Gt in 2040 with over half of the emissions coming from the power sector. In comparison, global emissions are projected to increase by 7% over the same period (International Energy Agency, 2019b). If no measures are taken to decarbonize Southeast Asia's power sector beyond its current policies, its fossil fuel infrastructure expansion will likely delay global power sector decarbonization as carbon capture and storage technologies are costly and have not yet been commercialized or widely deployed anywhere.

Southeast Asia's continued reliance on fossil fuel power generation, especially coal power, will bring environmental, financial, and energy security issues beyond CO₂ emissions. Coal-fired power generation, if not equipped with air pollution control technologies, emits air pollutants including sulfur dioxide, nitrogen oxides, particulate matter as well as various heavy metals which result in ambient air pollution that adversely impacts human health, natural ecosystems, and agricultural production. Fossil fuel power generation may also increase the financial burden on Southeast Asian country governments. With limited financial resources, Southeast Asian countries have resorted to international development finance institutions (DFIs) to fund their coal plants (Cornot-Gandolphe, 2016). As, starting in the 2010s, multilateral development banks adopted policies to stop financing coal plants, Southeast Asian governments have turned to national DFIs to finance new coal power (Chen et al., 2020), which could put a great financial burden on the local governments. Because the government provides sovereign guarantees for international financing, if the coal plants become stranded assets and power project companies default on their loans the government will be obligated to repay them. Additionally, since the 2010s, Southeast Asian countries have increasingly relied on imported coal for electricity generation, creating energy security risks (except for Indonesia where coal is abundant) (Cornot-Gandolphe, 2016). For example, with a number of coal-fired power plants in Vietnam commencing operation in the 2010s, in 2015 Vietnam transitioned from being a major regional coal producer and exporter to being a coal importer. In 2020, over 45% of the coal Vietnam consumed was imported (BP, 2021).

Studies with a global focus find that to meet the Paris goals, existing fossil fuel-based power generation infrastructure will need to retire prematurely in emission mitigation scenarios (Cui et al., 2019; Tong et al., 2019). Coal-fired power plants, in particular, will have only 20–35 years of operation if the Paris goals are met, much shorter than their economic lifetimes (Cui et al., 2019). Power plants that are currently under construction or planned in particular, if phased out prematurely, will result in significant stranded assets. If not, the committed CO₂ emissions from fossil power plants currently under development will result in CO₂ emissions significantly above levels consistent with the Paris climate goals (Pfeiffer et al., 2018).

Despite significant environmental, financial, and energy security risks associated with Southeast Asia's heavy reliance on fossil fuel power generation, Southeast Asia's power sector remain understudied. Studies with a regional focus have mostly focused on China and India in addition to developed regions (Binsted et al., 2020; Liu et al., 2019; Malik et al., 2020; Shearer et al., 2017; Yang & Urpelainen, 2019). Clark et al. (2020) find that emissions from Southeast Asia's coal-fired power plants will depend on their attrition rate, capacity factor, and plant lifetime. Caldecott et al. (2018) find that the majority of Southeast Asia's fossil fuel power generation assets planning is incompatible with emission pathways consistent with the Paris Agreement. Nevertheless, understanding regarding the long-term implications of the continued expansion of Southeast Asia's fossil fuel power pipeline for CO₂ emissions is limited. It is also unclear what Southeast Asia's current power generation pipeline implies for short-term electricity generation and renewable deployment.

In this paper, we address the knowledge gap regarding the impacts of Southeast Asia's expanding fossil fuel power fleet on electricity supply and regional CO₂ emissions. As previously no comprehensive inventory of Southeast Asia's power plants existed, to examine Southeast Asia's power generation pipeline (including plants in operation, under construction, and planned) as of 2020, we first compile a new database of the generation pipeline using three data sources (BloombergNEF, 2020; Global Energy Monitor, 2020a; S&P Global Market Intelligence, 2020). The compiled database includes coal, gas, oil, hydro, solar, wind, geothermal, biomass and waste-to-power technologies. We analyze 10 member countries of the Association of Southeast Asian Nations (ASEAN), namely Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam. Using this newly established database, we evaluate the committed CO₂ emissions of Southeast Asia's power generation pipeline over the power plants' lifetime. We examine the realized and remaining committed CO₂ emissions from operating fossil fuel plants in Southeast Asia as well as the committed emissions from plants that are under construction and planned as of 2020. We further analyze the dependence of committed emissions from coal plants on their utilization rates in order to see how displacement of coal with non-fossil energy reduces committed CO₂ emissions and how heavy reliance on coal power generation increases the emissions. Finally, we analyze the impacts of current power generation pipeline in Indonesia, Vietnam, and the Philippines on their electricity supply and renewable deployment between 2020 and 2030. We select Indonesia, Vietnam, and the Philippines because these three countries have the most coal plants that are currently operating, under construction, or planned in Southeast Asia. They are also among the few countries in Southeast Asia with quantitative capacity goals for renewable electricity. While 10 ASEAN member countries collectively committed to increasing renewable energy in their primary energy mix to 23% by 2030, a clear collective target for renewable electricity generation is absent. For Indonesia, Vietnam, and the Philippines, we estimate the projected electricity generation from their current power pipeline and renewable targets. By comparing projected electricity generation with these countries' projected electricity demand between 2020 and 2030, we analyze the implications for utilization levels of fossil fuel and renewable power plants.

2. Method and Data

2.1. Southeast Asia's Current Power Generation Pipeline

Here we use "Southeast Asia's current power generation pipeline" to refer to power plants in 10 ASEAN countries that were operating, under construction, and planned as of mid-2020. We construct the generation pipeline using three databases: World Electric Power Plants Database (WEPP; 2020 June Issue) (S&P Global Market Intelligence, 2020), Global Coal Plant Tracker Database (GCPT) (Global Energy Monitor, 2020a), and Bloomberg New Energy Finance Database (BNEF) (BloombergNEF, 2020).

Among the three databases, WEPP provides a global inventory of power plants at the generating unit level and tracks the operational status and holding company of individual plants. The historical releases of WEPP also track changes in the status of power plants' planning, construction, and operation. Therefore, WEPP is widely used for plant-level analyses such as lifetime CO₂ emissions, vintages, and retirement ages (Caldecott et al., 2018; Davis & Socolow, 2014; Jewell et al., 2019; Tong et al., 2019). WEPP has a comprehensive (>75%) to complete (>95%) coverage of power generating units for most technologies including coal, gas, oil, nuclear, hydroelectric, and geothermal, and a representative (>50%) to comprehensive coverage of most wind and solar power facilities around the world. For small wind and solar power generating units such as solar PV that is less than 10 MW or wind power that is less than 0.1 MW, its coverage is less than 50%. GCPT tracks the global coal plant pipeline and provides information on existing coal-fired power plants larger than 30 MW as well as coal plants proposed since 2010. It does not include non-coal power plants, currently planned coal plants that were proposed before 2010, or coal plants smaller than 30 MW. GCPT has been widely used in studies with a focus on coal power plants (Clark et al., 2020; Pfeiffer et al., 2018; Shearer et al., 2017; Yang & Urpelainen, 2019). BNEF tracks annual country-level power capacity and generation data for all power generating technologies and is often utilized for its comprehensive statistics and extensive analyses regarding renewable technologies (e.g., Zissler, 2019). However, it does not have spatially disaggregated or detailed plant-level information for Southeast Asia.

We synthesize these three databases and generate Southeast Asia's power generation pipeline which includes power plants that were operating, under construction, and planned in 2020 using the following steps. First, we obtain Southeast Asia's operating generation capacity for each power technology from 1980 to 2020 by merging WEPP data for coal, gas, oil, hydroelectric, and geothermal power technologies and BNEF data for wind, solar,

biomass and waste power (except for Brunei for which we use WEPP data because BNEF does not have data for Brunei). Data for coal, gas, oil, hydro, and geothermal power from WEPP is at the plant level and data for wind, solar, biomass and waste power from BNEF is at country level, as determined by the data sources. Nuclear power is not included in this study because there are currently no nuclear plants in operation or under construction in Southeast Asia. Countries like Indonesia once planned or considered nuclear power plants; however, nuclear power's prospects are now unclear across Southeast Asia due to its high costs and associated safety and security concerns (Maulia & Venzon, 2020). Second, we include power plants of all technologies that are under construction or planned as of mid-2020 using unit-level data from WEPP. Third, we use GCPT to check for coal plants missing from the WEPP database. The total coal power capacity documented in WEPP, GCPT, and BNEF are in good agreement for ASEAN countries other than Indonesia and Vietnam. For Indonesia and Vietnam, the total coal power capacity documented in WEPP is smaller than GCPT and BNEF, where GCPT and BNEF are consistent with each other. Therefore, for Indonesia and Vietnam, we merge WEPP with GCPT and add the coal plants documented in GCPT but missing in WEPP to the ASEAN power plant list. Through these three steps, we establish ASEAN countries' power generation pipeline as of 2020 to the best of our knowledge. We compare our results for Southeast Asia's generation capacity with regional level data from IEA (International Energy Agency, 2019b) and find our results to be in good agreement with IEA's estimates of capacity growth between 2019 and 2040 based on existing policies and plans.

Planned power plants include those that were still in development or being designed as of mid-2020. Financing for these plants may not have been secured. Power plants, especially large infrastructure such as coal-fired power plants and hydroelectric plants, typically take years to plan and construct (Figure S1 in Supporting Information S1). Because it takes months to years to reach financing agreements for a new power plant, planned power plants included in this study are not a forecast of what will happen in the future, but an indication of each ASEAN country's power generation sector planning as of 2020. Initiation of new plants or cancellation of planned ones after 2020 is possible.

To analyze the potential impact of 10 ASEAN countries' current power generation pipeline on their generation capacity growth in the near future, we determine each power plant's commissioning year and retirement year using the following procedure. We use the plant's commissioning year or planned commissioning year from WEPP or GCPT if such information is available. When such information is not available, we exclude coal, gas, hydroelectric and non-hydro renewable power plants which have been in the planning stage for over 12, 10, 12, and 8 years, respectively, and the commissioning year remains unknown. The planning time thresholds are determined based on the 95th percentile of power plants' planning and construction time historically (see Text S1 and Figure S1 in Supporting Information S1 for the historical planning and construction time of power plants in Southeast Asia). We consider such plants unlikely to proceed without cancellation or further deferral. We determine the commissioning year of power plants with shorter planning times by assuming a commissioning year between 2020 and 2027 following the average planning and construction time based on historical data (see Supporting Information S1 for more details). We determine each power plant's future retirement year using its commissioning year and an assumed expected lifetime based on its technology (Davis & Socolow, 2014; Handayani et al. 2020; Shen et al., 2020). The expected economic lifetime for each power technology is listed in Table S1 in Supporting Information S1. Based on the expected economic lifetime, coal, gas, and oil plants will retire after operating for 40 years. Hydroelectric plants will retire after operating for 65 years. Other renewable plants such as solar, wind and geothermal will retire after operating for 20–30 years. The actual retirement year will depend on each power plant's operating conditions and national policies (e.g., regional power shortage may lead to longer operational years before a plant retires and clean energy policies and climate policies may enable early retirement of fossil fuel plants). Currently operating plants with longer operational years than their expected lifetimes are assumed to retire randomly between 2020 and 2030. Here we focus on ASEAN countries' power generation pipeline as of mid-2020; therefore, new fossil fuel and renewable projects initiated after mid-2020 are not included.

2.2. Committed CO₂ Emissions From Operating, Constructed, and Planned Fossil Fuel Plants

We evaluate the long-term climate consequences from Southeast Asia's current power generation pipeline by quantifying the committed CO₂ emissions expected over the fossil fuel plants' lifetime (Davis & Socolow, 2014). We use our constructed list of coal, gas, and oil power plants in ASEAN countries and calculate each power plant's lifetime committed CO₂ emissions based on the function:

$$E_i = C_i \times CF_{f,k} \times 8760 (\text{hours}) \times H_{f,t} \times EF_{f,j} \times L_f$$

where i, f, j, k, t represent power generating unit, fuel type (coal, gas, or oil), fuel (anthracite, bituminous, lignite, etc.), country, and power plant technology (subcritical, supercritical, or ultra-supercritical coal power; steam turbine, simple-cycle gas turbine or combined cycle gas turbine). E (unit: kg CO₂) represents lifetime committed CO₂ emissions and measures the total CO₂ emissions expected over the power plant's economic lifetime; C (unit: MW) represents the plants' generation capacity; CF (unitless) is a capacity factor and represents the utilization rate of each plant; H represents heat rate (unit: Btu/MWh); EF represents CO₂ emission factor (unit: kg/Btu); and L represents lifetime in years.

We calculate the capacity factor between 2017 and 2019 for each fuel type in each ASEAN country using BNEF statistics of electricity generation (BloombergNEF, 2020) and use the average capacity factor over the past three years for each fuel type in each country. Because utilization rate data at the plant level is not available, we assume that power plants of the same fuel type in the same country have the same utilization rates. In our base case scenario, we assume power plants' capacity factors vary by country but remain constant throughout the plants' lifetime as no information regarding the plants' future utilization rate is available. As each power plant's annual operating hours increase or decrease in the future, its CO₂ emissions will change accordingly. To evaluate how lifetime committed CO₂ emissions may change with power plant utilization rates (capacity factors), we conduct a sensitivity analysis examining how larger displacement of coal with non-fossil energy could reduce committed CO₂ emissions and how heavier utilization of coal power plants could increase committed CO₂ emissions.

We estimate the heat rates of power plant technologies based on various sources (MIT, 2007; Tong et al., 2018; U.S. Energy Information Administration, 2020). The heat rates and corresponding electricity generating efficiencies are listed in Table S2 in Supporting Information S1 and they agree with efficiencies in select ASEAN countries where data is available (Maruyama & Eckelman, 2009). We use emission factors of each fuel following the IPCC Guidelines for National Greenhouse Gas Inventories (Eggleston et al., 2006). After obtaining the total lifetime committed CO₂ emissions for each plant, we then divide them into the realized emissions through 2019 and remaining committed emissions from 2020 onwards.

2.3. Electricity Generation and Demand in Indonesia, Vietnam, and the Philippines

We estimate future projected electricity generation in Indonesia, Vietnam, and the Philippines between 2020 and 2030 based on their current power generation pipeline and near-term renewable capacity goals. We analyze three scenarios to understand the impact of increased renewable penetration and increased utilization of coal plants. In the base case scenario, we project future electricity generation using these three countries' current power generation pipelines and do not consider new fossil fuel or renewable plants that may be initiated after 2020. In the base case, we assume for each country the capacity factor for each technology will remain the same as the historical capacity factor (as estimated in Section 2.2) and stay constant until 2030. Actual capacity factors depend on each power plant's or technology's utilization rate and thus can change with time. New plants may also have different capacity factors than existing power plants because of their location and/or the grid capacity. Therefore, our analyses are heuristic and are not forecasts of future electricity generation in the three countries. The base case scenario represents future electricity supply in Indonesia, Vietnam, and the Philippines projected from their current power generation pipeline.

In the second scenario, we project increased renewable penetration by combining electricity generation from each country's current power pipeline with additional generation from renewable sources based on their near-term capacity goals. As the three countries may construct additional new power plants beyond their current pipeline, especially renewable plants which generally take less time to plan and construct than fossil fuel plants, this scenario incorporate planning of additional renewable energy in these three countries. The modest renewable capacity goals used for these three countries are either national policies (the Philippines) or the most ambitious goals announced or presented by their government branches (Indonesia) or officials (Vietnam) and may or may not be regulated by law. These renewable targets and data sources are listed in Table S3 in Supporting Information S1. For each country, we project their pathways to meet these renewable capacity targets assuming that generation capacity for each renewable technology will increase linearly from 2020 to the target year (2025 for Indonesia and 2030 for Vietnam and the Philippines). We do not consider renewable capacity increases in Indonesia from 2025

to 2030 as no concrete renewable target exists yet after 2025. This scenario explores the implications of modest increases in renewable generation in the three countries.

In the third scenario, we consider both expanded renewable deployment (based on the capacity targets set in the second scenario) and increased coal-fired power plant utilization rates (increased from the historical capacity factor to 75% while keeping the capacity factors of other technologies the same as the other two scenarios). Seventy-five percentage is the highest annual average capacity factor of coal plants for the Asia Pacific region excluding China according to BloombergNEF (2020) and therefore is chosen to represent an increased but realistic utilization level of coal plants.

We compare electricity generation projection estimates in the above three scenarios with future projected electricity demand in Indonesia, Vietnam, and the Philippines. The three countries' future electricity demand is estimated based on their national electricity consumption in 2018 and a variety of annual electricity demand growth rates that reflect a range of future demand growth pathways. To take into account the uncertainty of future electricity demand growth, we choose a relatively wide range of demand growth rates for each country. Our rates use estimates from national government projections (which tend to have higher estimates than other sources), research institute reports, and recent demand growth trends (Asian Development Bank, 2020; Asian Power, 2020; Danish Energy Agency, 2017; Department of Energy, 2019; International Trade Administration, 2021; Kritz, 2020; Lee, 2019; Lolla & Yang, 2021; Minh, 2019). The range of growth rates for each country and the corresponding references are listed in Table S4 in Supporting Information S1.

Electricity demand forecasting models and techniques such as the Long-range Energy Alternatives Planning (LEAP) model, time series models, regression analysis, or machine learning based techniques (Kumar, 2016; Mir et al., 2020) are widely used to forecast long-term electricity demand. Here, we take a heuristic approach and estimate a range of possible electricity demand projections for Indonesia, Vietnam, and the Philippines because our goal is not forecasting actual electricity demand. Rather, we choose the range of demand growth rates to analyze the relationship between future electricity supply and demand as a result of Southeast Asia's current generation pipeline. Actual electricity demand growth rates vary from year to year. However, future demand in each country will most likely fall within the wide ranges we present.

3. Results

3.1. Southeast Asia's Power Generation Pipeline

Fossil fuels and hydroelectric power have long underpinned Southeast Asia's power generation development. Together, they made up over 95% of Southeast Asia's total generation capacity of 19 GW in 1980 and in 2019 still contributed over 85% of the total 280 GW capacity (excluding generation capacity from waste heat recovery systems in combined cycle power plants). A total of 186 GW of fossil power (84 GW of coal, 77 GW of gas, and 25 GW of oil power plants), as well as 51 GW of hydroelectric power, were in operation in Southeast Asia in 2019. Meanwhile, non-hydro renewable technologies played an insignificant role with only 21 GW total capacity in 2019. ASEAN countries have diverse portfolios of power generation given their distinct resources and energy development strategies. Most of the coal plants in Southeast Asia were located in Indonesia (32 GW), Vietnam (19 GW), Malaysia (13 GW), and the Philippines (10 GW) as of 2019. Gas power played the most important role in Thailand's and Singapore's power sectors, making up 53% (28 GW) and 63% (9 GW) of their total generation capacity in 2019. Meanwhile, Laos, Myanmar, and Cambodia have prioritized hydroelectric power development, with 78% (7 GW), 49% (3 GW), and 61% (1 GW) of their capacity mixes coming from hydroelectric power in 2019, respectively.

Our analyses of Southeast Asia's current power generation pipeline show that coal, gas, and hydroelectric power will continue to play an important role in the near future (Figure 1). Power plants that were under construction and planned as of mid-2020 will double the generation capacity of coal (with 100 GW added) and hydroelectric power (52 GW) in ASEAN countries from 2019 to 2029 and increase the generation capacity of gas power by almost 80% (60 GW). Most of the generation capacity growth is from power plants currently under construction or planned in Vietnam, Indonesia, and the Philippines (see Table S5 in Supporting Information S1 for the breakdown by country). Additionally, a number of hydroelectric power projects will be added in the Mekong region, including Myanmar and Laos. Twenty-one gigawatts of gas plants will be added in Thailand and Malaysia. Here our analyses do not include new power plants that may be initiated after mid-2020, and Southeast Asia's future

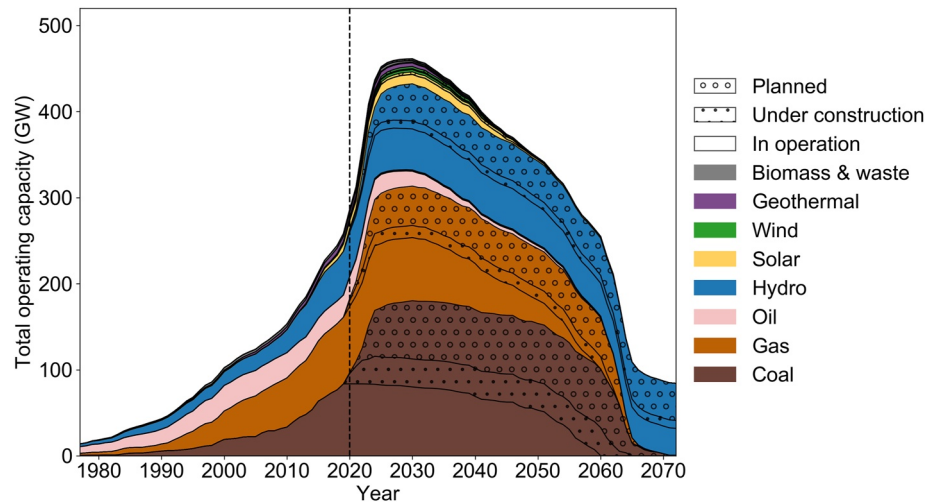


Figure 1. Power generation capacity in ten ASEAN countries, by technology type and by operational/development status as of mid-2020. The area to the right of 2020 indicates Southeast Asia's future power generation capacity based on power plants that were in operation, under construction, and planned as of 2020. Additional fossil fuel or renewable power plants that may be initiated after 2020 are not included. Capacity from waste heat cogenerating units in combined cycle thermal plants is not included.

power generation projection will likely include additional power plants of various technologies. According to the projection by IEA based on Southeast Asian countries' stated policies, over 90 GW of coal power and over 100 GW of gas power may be installed between 2019 and 2040 (International Energy Agency, 2019b).

However, Southeast Asia does not need to become heavily reliant on fossil fuels for power generation. Currently, the planned generation pipeline only includes a limited number of non-hydro renewable projects (12 GW of solar, 6 GW of wind, 5 GW of biomass, and 4 GW of geothermal around 2029). There is therefore a large potential to develop additional renewable power in the near future given Southeast Asia's considerable renewable resources (Kumar, 2016) and the rapidly decreasing costs of renewable technologies (Carbon Tracker, 2018). Fossil fuel plants that are still at the planning stage could be replaced with renewable energy technologies before fossil fuel power infrastructure is actually built.

3.2. CO₂ Emissions From Southeast Asia's Current Power Generation Pipeline

Figure 2 shows projected CO₂ emissions from coal, gas, and oil power plants that were in operation, under construction, and planned in ASEAN countries as of 2020. Operating fossil fuel plants have emitted 9 Gt of CO₂

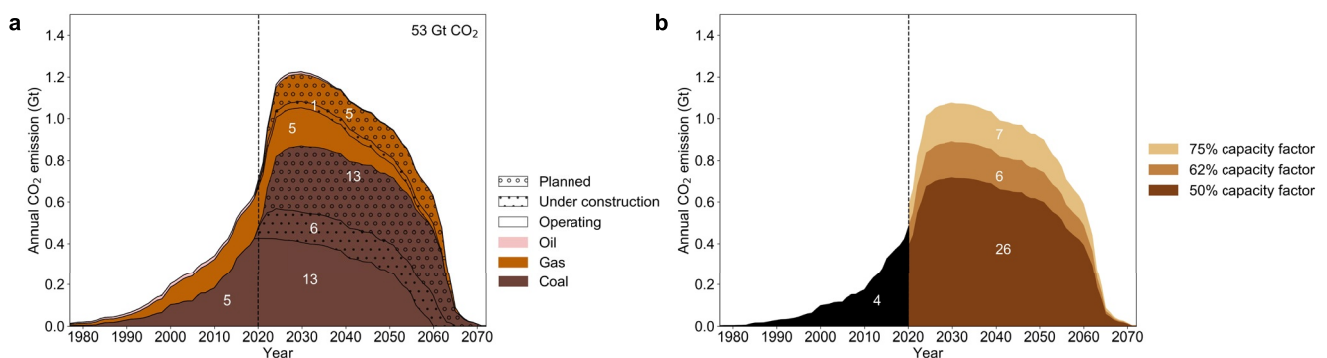


Figure 2. (a) Annual CO₂ emissions expected from fossil fuel power plants that were in operation, under construction, and planned as of 2020 and (b) emissions from coal plants operating at a variety of average capacity factors. Numbers in the panels indicate total committed CO₂ emissions (Gt CO₂). The area left of 2020 indicates cumulative emissions through 2019 and the area right of 2020 is projected remaining committed emissions over the remainder of the power plants' assumed 40-year lifetime.

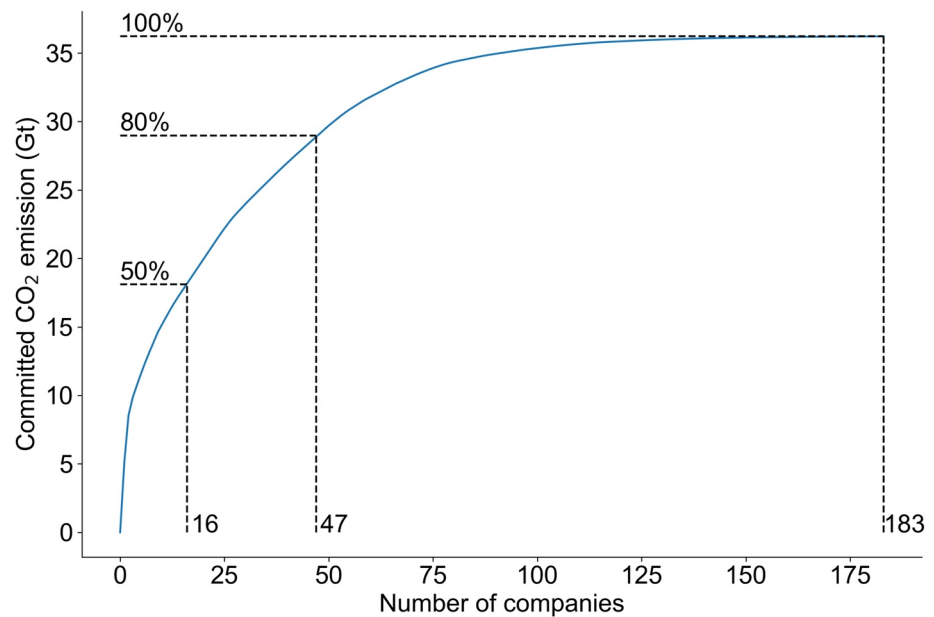


Figure 3. Committed CO₂ emissions contributed by holding companies that operate/own coal-fired power plants in Southeast Asia. Fifty percentage of committed emissions come from only 16 of the holding companies. Expected committed emissions from coal-fired power plants that were operating, under construction, and planned as of 2020 are included.

since 1980, with 5 Gt, 3 Gt, and 1 Gt from coal, gas, and oil power plants respectively. Continuing to operate these existing power plants leads to an additional 18 Gt of CO₂ committed emissions throughout the rest of their lifetimes. The large number of coal and gas power plants under construction or planned as of mid-2020 will further increase the total committed CO₂ emissions from Southeast Asia's power sector. Coal and gas plants that are under construction will emit 6 Gt and 1 Gt of CO₂ over their lifetimes. Moreover, currently planned coal and gas plants will emit another 13 Gt and 5 Gt of CO₂, respectively. Together, Southeast Asia's fossil fuel power pipeline, which had not yet begun operation as of 2020, will nearly double committed CO₂ emissions from Southeast Asia's power sector over the long term if the plants that were under construction and planned as of 2020 proceed according to plan and operate at similar utilization levels as plants have in the past.

Actual future CO₂ emissions from coal, gas, and oil power plants will depend on how much they are utilized throughout their lifetimes—as indicated by their capacity factors. Using Southeast Asia's coal power pipeline as an example, we show that a 20% increase of capacity factor from its historical average level of 62%–75% adds 7 Gt of additional committed CO₂ emissions (Figure 2). This corresponds to a heavier reliance on coal power for electricity generation in the future, in which case the average operating hours of coal plants increase from 5,400 hr to 6,600 hr annually. Conversely, with deeper penetration of renewable technologies to the power system, countries may displace coal with renewables and utilize coal power plants less in the future than they do currently. In this case, a 20% decrease of coal plants' capacity factors to 50% will reduce their committed CO₂ emissions by 6 Gt.

A small number of holding companies that operate and own the coal-fired power plants in Southeast Asia contribute to the majority of committed CO₂ emissions (Figure 3). Out of the 183 companies that operate and own coal plants, less than 10% of them (16) contribute 50% of the total CO₂ emissions, while 25% of the companies (47) contribute 80% of total emissions.

3.3. Projected Electricity Supply in Indonesia, Vietnam, and the Philippines

Figure 4 shows projected future electricity supply based on the current power generation pipeline in Indonesia, Vietnam, and the Philippines, as well as projected generation when taking into account increased renewable penetration and increased coal plant utilization rates. All three countries demonstrate reliance on fossil fuel power generation, especially that from coal. Figure 4 shows that projected future electricity supply exceeds projected future demand in the coming years before 2030 in Indonesia, Vietnam and the Philippines if power plants under

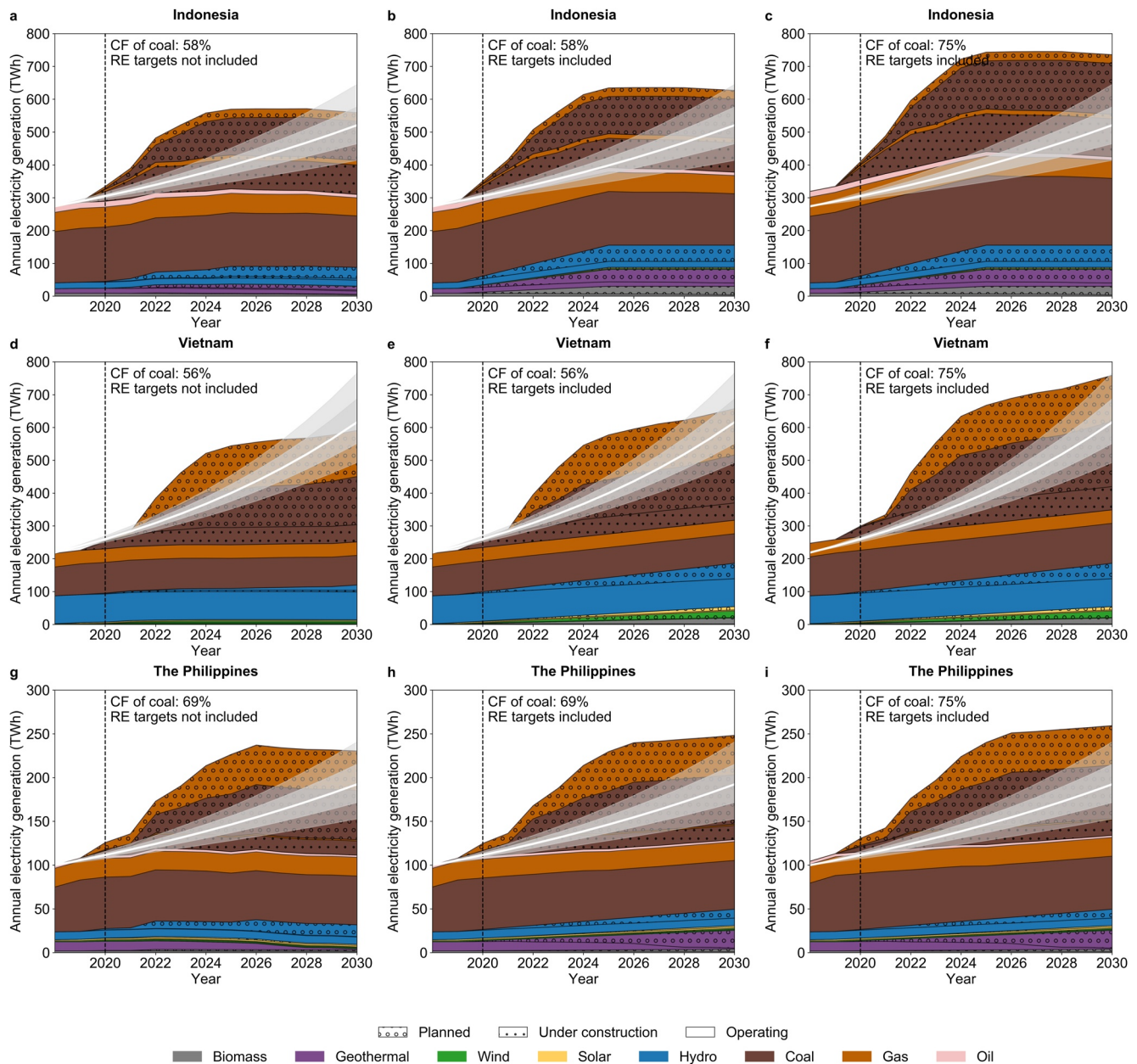


Figure 4. Projected annual electricity generation from Southeast Asia's power plants. Panel (a), (d), and (g) project future electricity generation based on historical capacity factors of each technology in Indonesia, Vietnam, and the Philippines for power plants that were in operation, under construction, or planned in 2020. Panel (b), (e), and (h) project future generation based on each country's current power pipeline as well as their renewable capacity targets by 2025 (Indonesia) or 2030 (Vietnam and the Philippines). Panel (c), (f), and (i) project future generation based on historical capacity factors for non-coal technologies and 75% capacity factor for coal power. Panel (c), (f), and (i) include each country's current power pipeline as well as their renewable capacity targets by 2025 (Indonesia) or 2030 (Vietnam and the Philippines). The light gray bands are projections of each country's national electricity demand estimated based on a range of annual demand growth rates. The ranges of annual demand growth rates for each country are: Indonesia 3.5%–7.5%; Vietnam 6%–10%; and the Philippines 3.6%–7.6%.

construction and planned in 2020 commence operation as planned and operate at historical capacity factors. The electricity “oversupply” (when projected electricity supply is larger than projected demand) increases when renewable penetration becomes larger and coal plant utilization levels increase. Therefore, part of the fossil fuel plants under construction and planned in 2020 will not be needed for electricity generation in the near future. This implies underutilization of fossil fuel power plants in the future and/or a crowding-out of renewable deployment. We discuss power sector development in Indonesia, Vietnam, and the Philippines and the implications separately below.

3.3.1. Indonesia

Indonesia has a vertically integrated electricity market, where the State Electricity Company— PT Perusahaan Listrik Negara or PLN—owns over half of the power generation assets and generates the majority of electricity in the country and is responsible for electricity transmission and distribution (IRENA, 2017a) while electricity tariffs are controlled by the government. Indonesia's power generation pipeline as of 2020 suggests that the majority of Indonesia's electricity generation comes from coal-fired power plants before 2020 and through 2030. With 31 GW of coal and 14 GW of gas power plants in 2018, 84% of Indonesia's electricity generation came from fossil fuels in 2018. Going forward, Indonesia's current power pipeline may result in electricity oversupply from its fossil fuel-based power system. If power plants in Indonesia continue operating at historical capacity factors, electricity generation from plants that were under construction and planned in 2020 will only be fully utilized after 2028 (Figure 4a). In 2016, the Indonesian Ministry of Energy and Mineral Resources (MEMR) drafted the National Electricity General Plan (RUKN) 2015–2034, which indicated plans to install 45 GW of renewable power generation capacity by 2025. If Indonesia meets this renewable target (Figure 4b), fossil fuel plants that were under construction in 2020 will generate sufficient electricity to meet fast-growing demand through 2026. In a relatively low demand growth scenario, plants that were under construction are sufficient to meet demand through 2030. Planned coal-fired power plants in Indonesia will be stranded capacity through 2026 under high demand growth, or through 2030 under low demand growth, and they will not be fully utilized until after 2030. Additionally, if Indonesia prioritizes utilizing currently operational coal plants and increases their capacity factor to 75%, no new electricity generation will be needed before 2026 even at high demand growth rates (Figure 4c). The 18 GW of coal plants under construction will not be needed until after 2026 and the 24 GW of coal plants that were planned in 2020 will not be needed until after 2030. Moreover, Indonesia's national electricity demand has grown at a much slower rate in recent years than the government expected (Asmarini, 2020). If the trend of low demand growth continues, electricity supply from coal plants that were under construction in 2020 will not be needed until after 2028, and electricity supply from planned coal plants will not be needed until years after 2030. In 10 years, coal power plants may become a poor economic choice leading Indonesia to risk building assets which will be stranded soon after commissioning. Therefore, renewable alternatives may be economically preferable as well as environmentally friendly.

Importantly, Indonesia's current power sector development, especially the large number of coal plants under construction and planned, may crowd out renewable energy deployment. Indonesia's long-term plans for power generation and grid development (such as the Electricity Supply Business Plan [RUPTL] issued by PLN) often include detailed planning and outline specific projects for fossil fuel, hydroelectric and geothermal projects, where the same level of detail is lacking for non-hydro renewable projects (IRENA, 2017a). Furthermore, PLN's renewable targets in RUPTL are much lower than that in RUKN, which is not formally regulated, indicating that PLN's grid plans may not be designed to achieve the renewable targets in RUKN (IRENA, 2017a). If the construction and planning of new coal plants continue, the excess capacity of coal power may become “stranded assets.” Coal plants will likely operate at lower utilization levels in the future, especially as PLN is already experiencing electricity oversupply (Asmarini, 2020). Most recently, the CEO of PLN announced that Indonesia will complete the construction of already planned coal power plants by 2023 but thereafter will not add any new coal power plants to its national grid (Jong, 2021). However, it is unclear whether this plan would cease construction of coal plants that are currently under construction or planned, or would accelerate their construction so they are completed prior to 2023.

3.3.2. Vietnam

Similar to Indonesia, Vietnam also has a vertically integrated electricity market. The state-owned power company, Electricity of Vietnam or EVN, controls the majority of power generation assets, the National Power Transmission Corporation, National Load Dispatch Center, as well as the Electricity Power Trading Company, which is the single buyer on the electricity market (Asian Development Bank, 2015). Power sector reform has developed for decades since before the 1990s. Following the Electricity Law passed in 2004, Vietnam introduced a competitive generation market which started full operation in 2012 and is now developing a competitive wholesale market which is planned to start operation by 2021 (Lee & Gerner, 2020).

Vietnam, among ASEAN countries, had the largest coal and gas power generation capacity under construction and planned in 2020. Driven by fast economic growth and increases in electricity demand, Vietnam has expanded its fossil fuel power generation rapidly since the 2000s. Specifically, the share of its electricity generation from

coal power grew from 15% in 2010 to 41% in 2019. Vietnam has continued to meet its fast electricity demand growth with a large number of coal and natural gas plants with coal increasingly imported from other countries (Zissler, 2019). However, it still faces power shortages due to delayed construction of new plants (Lee, 2019; Vu, 2019). Based on Vietnam's current power generation pipeline, coal and gas power continue to dominate its future power generation mix. As shown in Figure 4, Vietnam relies on coal plants under construction to meet its near-term electricity demand. If Vietnam meets the renewable capacity targets as indicated by the Ministry of Industry and Trade (Thuc, 2020) and operates existing coal plants at a higher capacity factor of 75%, coal plants under construction are sufficient to meet its electricity demand through 2024 (Figure 4f). However, planned coal and gas power will not be fully utilized until around 2030. In other words, either currently planned coal power or planned gas power (or both) will become stranded assets which operate at utilization rates below optimal levels, especially with future renewable power development.

Compared with fossil fuel power infrastructure, renewable projects like wind and solar power take less time to complete and can serve to fill the near-term electricity generation gap in Vietnam. Moreover, wind and solar projects will become cheaper than coal in the coming years (EREA & DEA, 2019). Therefore, replacing part of the planned fossil fuel capacity with renewable projects in Vietnam will help relieve the financial burden from building new coal plants. As Vietnam formulates its Power Development Plan (PDP) VIII for the next 10 years (2021–2030), it is important to take renewable power into account as an alternative to new fossil fuel plants given renewable's advantages in shorter construction time and decreasing costs.

3.3.3. The Philippines

The Philippines' power sector is liberalized and substantially privatized due to the Electric Power Industry Reform Act passed in 2001. It has both a competitive generation market and a competitive retail market and electricity tariffs in the Philippines are market driven. Power sector development in the Philippines has gone through several stages since the 1990s. In the early 1990s, after experiencing several severe power outages, the Philippines passed the Electric Power Crisis Act. This led to a rapid power capacity expansion in the late 1990s from 8 GW in 1990 to 18 GW in 2000. The expansion was facilitated by the private sector and mainly comprised oil power plants. In the 2000s, when electricity demand did not grow as quickly as forecast, parts of the Philippines experienced excess capacity (Asian Development Bank, 2018). As a result, the Philippines' power generation capacity grew moderately between the early 2000s and mid-2010s, from 18 GW in 2000 to 22 GW in 2015, primarily using coal. As electricity demand grew and excess generation capacity decreased, its power sector started the second phase of rapid expansion in the mid-2010s. Coal power capacity increased from 6 GW in 2015 to 10 GW in 2019, with 12 GW capacity under construction and planned as of 2020. Coal and gas power made up 72% of the Philippines' power generation mix in 2018 and continues to dominate its planned future electricity generation. Renewable power generation in the Philippines is mainly from geothermal and hydroelectric power plants. The first geothermal plant was built in 1977 and the Philippines now generates the second most geothermal power in the world after the United States (IRENA, 2017b).

The Philippines' planned coal and gas power plants risk becoming stranded assets, too. With a relatively slow electricity demand growth forecast, coal plants that were under construction in 2020 will be sufficient to meet the Philippines' demand through 2023 (Figure 4g). In 2011, the Philippines set a renewable target of 15.3 GW by 2030. With electricity output from its current power generation pipeline as well as this renewable target, a substantial fraction of its planned coal and gas power plants will be underutilized or will not be needed at all before 2030 (Figure 4h). Continuing to plan and build coal and gas power as scheduled will likely result in excess reserve margin in the Philippines as it had in the 1990s. As the lockdown measures due to Covid-19 led to economic slowdown and a decrease in electricity consumption in 2020 in the Philippines (Asian Power, 2020), the need for new coal and gas plants to meet electricity demand will be further delayed if more renewables are deployed and the need for the planned coal capacity may be eliminated completely. In late 2020, the Philippines government announced a moratorium on approvals for new coal plants (Farand, 2020). Additional efforts to strengthen and scale up its renewable energy target as well as to replace some of the planned coal or gas power plants are needed to accelerate a coal power phase-out and power sector decarbonization.

4. Discussion

4.1. Implications of the Power Generation Pipeline for Electricity Generation and Renewable Development

If Southeast Asian countries continue to rely on fossil fuels to meet their electricity demand without a transition toward renewable power alternatives, they will be locked into a future reliant on fossil fuel infrastructure both to their economic detriment and to the detriment of the global climate. LCOE of coal plants were lower than most renewable projects in Southeast Asia prior to 2020 (Zissler, 2019). However, our analyses imply that the future economics of coal plants will likely change as excess capacity increases and their utilization rates decline. If coal plants in Indonesia, Vietnam, and the Philippines operate at utilization levels that are equivalent to or higher than in the past, electricity “oversupply” will result in the near term as demand is projected to be lower than supply at such utilization rates. This will lead to either underutilization of fossil fuel plants or a crowding-out of renewable energy deployment, or both.

In this paper, we project the three countries' future electricity demand based on their 2018 demand and an average demand growth rate of 5.5% for Indonesia (3.5%–7.5% range), 8% for Vietnam (6%–10% range), and 5.6% for the Philippines (3.6%–7.6% range). We did not consider the actual decline in demand in 2020 due to the effects of COVID-19. In reality, estimates indicate that Indonesia's electricity demand in 2020 decreased from its 2019 level (Asian Development Bank, 2020) and Vietnam's electricity demand in 2020 increased by only 3% from its 2019 level (International Energy Agency, 2020b). These reductions in projected demand will make electricity “oversupply” from coal plants larger, and thus stranded coal power assets more severe than what our results indicate.

The expanding fossil fuel power fleet in Southeast Asia will cause financial losses from underutilization of fossil fuel infrastructure, especially as renewable energy such as wind and solar become increasingly competitive with coal and natural gas plants. Even in Indonesia, Vietnam, and the Philippines where coal has long been subsidized and renewable feed-in tariffs have not always been attractive, new solar and wind plants may soon become cheaper than investing in new coal plants (Carbon Tracker, 2018). Furthermore, new solar and wind power generation in these countries will also become cheaper than operating existing coal plants by the late 2020s (Carbon Tracker, 2018).

We show that many of the coal plants under construction in Indonesia are not needed to meet national electricity demand in the near term. Additional coal and gas capacity in Indonesia, Vietnam, and the Philippines planned in 2020 are not needed until after the late 2020s. In the long term, fossil fuel infrastructure is less flexible than non-hydro renewable alternatives because fossil fuel plants, especially coal-fired power plants, take much longer to plan and construct before they start generating electricity. In the past, on average coal plants have taken 4 years to plan and 3 years to complete construction before operation commences (Figure S1 in Supporting Information S1). In recent years, several coal plants have experienced serious delays, which led to a lag of 8 years or longer before construction started. Factors including difficulty in securing financing, opposition from local communities due to environmental and ecological concerns, challenges surrounding land acquisition, difficulty in securing long-term coal supplies, and delays in signing power purchase agreements have all made fast planning and construction of coal plants challenging, if not impossible (Buckley & Shah, 2018; Chavez, 2020; Nangoy & Burton, 2019; Woods, 2017). While countries rely on coal plants to bring large firm capacity to the grid, the risk of project delay or stagnation may disrupt these plans. Alternatively, non-hydro renewable projects can help relieve near-term power shortages because they can be built more quickly. As the costs of renewable technologies continue to decrease, planning renewable projects to meet future electricity demand growth will become increasingly cost effective. As we show in the electricity generation analyses for Indonesia, Vietnam, and the Philippines, even modest renewable targets may delay or eliminate the need for new coal or gas plants and bring local economic and global climate benefits.

4.2. Uncertainties in the Future Generation Pipeline

Policies for power sector development in Southeast Asia are changing fast. Since the time of data collection and analysis for this study, a number of coal-fired power plants across Southeast Asia and beyond are being canceled. Vietnam's draft PDP VIII issued in February 2021, if enacted, will reduce the planned new coal power capacity built between 2020 and 2030 from 30 to 17 GW, compared to its previous PDP VII issued in 2016 (Ministry of Industry and Trade of the Socialist Republic of Vietnam, 2021). The draft PDP VIII allows coal-fired power

plants that were already under construction or licensed to proceed. However, a large number of the licensed coal plants have not yet secured financing (Global Energy Monitor, 2020b). In 2020 the government of Bangladesh announced it would cancel all planned coal-fired power plants that were not already under construction (Karim, 2021; Roy, 2020). In India, a number of planned coal plants were cancelled before 2020 (Global Energy Monitor et al., 2021). These cancellations may be an indication of awareness of coal plants' economic and environmental risks. Nevertheless, as we show in Figure 4, if planned coal plants are all canceled but plants that were under construction proceed and commence operation in the near future, countries like Indonesia will still face electricity “oversupply” between 2020–2030. If Indonesia scales up its plan for renewable capacity, such “oversupply” will be more severe. Similarly, additional initiations of renewable projects in Vietnam and the Philippines may make coal plants that were under construction stranded assets in the future. Vietnam's draft PDP VIII states that its solar capacity in 2020 reached 17 GW, which is much higher than our estimate of 3 GW based on WEPP and BNEF data and higher than our estimate of planned 12 GW solar capacity for 2030. Therefore, electricity generation in Vietnam from solar power is likely higher than what we show in Figure 4, although the additional generation from solar will be limited because solar power's capacity factor is much lower than that of coal or gas power plants. The draft PDP VIII indicates that 20 GW solar capacity will be achieved by 2030, which is not a significant increase from its actual 17 GW solar capacity in 2020. If more solar power is developed and deployed, the planned coal power capacity will face a higher economic risk.

Planned coal-fired power plants that have not been canceled yet in Southeast Asia will also face financing challenges if they proceed, as international financing for coal power is shrinking. Development banks, commercial banks and companies from Asia have greatly supported coal power development in Southeast Asia in the past (Chen et al., 2021; Global Energy Monitor, 2020b). In early 2021 Japan and South Korea, among the biggest East Asian public financiers, announced an end to public financing for overseas coal plants (S. Liu et al., 2021). In September 2021, China also announced that it will not build new coal plants overseas (Volcovici et al., 2021). As international financing for coal power tightens, planned coal-fired power plants included in this study may also be affected, especially the ones for which the financial agreements have not been finalized. Thus, rather than proceeding with coal-fired power plants which will likely become stranded assets, a timely transition to renewable alternatives may be possible.

4.3. Climate and Other Environmental Implications

A timely clean energy transition in Southeast Asia is crucial to meet the global climate targets. Southeast Asia's power generation pipeline emitted 9 Gt of CO₂ from 1980 through 2019. If fossil fuel plants operate at utilization levels similar to the past for 40 years for the rest of their economic lifetime, the remaining committed CO₂ emissions from Southeast Asia's generation pipeline will be 44 Gt. This is about 12% of the remaining budget of 360 Gt CO₂ for a 67% chance of limiting 1.5°C global warming according to IPCC's Sixth Assessment Report (Forster et al., 2021). Some of the remaining committed CO₂ emissions from Southeast Asia's power sector can be avoided if fossil fuel power generation is displaced by renewable sources. We show that a 20% decrease in the utilization of coal plants can reduce committed emissions by 6 Gt. In 2021, Asian Development Bank is planning a partnership with private banks to buy out coal-fired power plants in Southeast Asia and retire them prematurely within 15 years (Lawder, 2021). If successful, this can greatly cut committed CO₂ emissions from coal plants and facilitate the transition to alternative low carbon technologies.

Southeast Asia's power generation pipeline in 2020 also implies a rapid increase of annual CO₂ emissions from the power sector between 2020 and 2025 and a continued increase through 2030. This is consistent with their Nationally Determined Contributions (NDCs) under the Paris Agreement, which generally allow for rapid emission growth before 2030. As of October 2021, all ASEAN countries except for Brunei and the Philippines have submitted their updated NDCs, and Brunei and the Philippines submitted their first NDC in 2020 and 2021, respectively. Among all ASEAN countries, Singapore is the only one with a peak emission level target. In the updated NDC, Singapore commits to peak emissions at 65 Mt CO₂ around 2030 and achieve a 36% reduction in emissions intensity by 2030 from 2005 level. Malaysia's updated NDC commits to a 45% carbon intensity reduction in 2030 compared to 2005 level. Most other ASEAN countries' NDCs are in reference to a business-as-usual (BAU) scenario, which allows for substantial increases in emissions. For example, Vietnam's first NDC commits to 8% unconditional and 25% conditional GHG emission reductions by 2030 compared to BAU. Its updated NDC commits to a 7.3% unconditional GHG emission reductions by 2025, and 9% unconditional and 27% conditional

reductions by 2030 compared to BAU. Indonesia's updated NDC submitted in July 2021 repeats its existing targets outlined in the first NDC for an unconditional 29% emission reduction by 2030 and a conditional 41% emission reduction below BAU, and has put minimal restrictions on fossil fuel power expansion. In the first NDC submitted in April 2021, the Philippines commits to peak its emissions by 2030. In addition, it commits to achieve a cumulative GHG emissions reduction from 2020 to 2030 by 2.7% unconditionally compared to the BAU cumulative emissions within the same period, as well as a conditional 75% reduction. Approximately, the BAU scenario is equivalent to an annualized 7.7% emission growth between 2020 and 2030. Thus the power generation pipeline in Indonesia, Vietnam, and the Philippines developed as of 2020 and their NDCs all seem insufficient to meet global decarbonization goals when limiting global warming to 1.5°C requires rapid and unprecedented changes across all economies.

In this paper, we highlight the long-term CO₂ emissions of Southeast Asia's expanding fossil fuel power fleet. Besides direct CO₂ emissions, fossil fuel and hydroelectric power infrastructure have other environmental and climate-related risks. Coal-fired power plants cause short-term environmental problems in addition to the long-term climate impacts of their CO₂ emissions. Without pollution control devices, coal plants emit air pollutants which contribute to elevated air pollutant concentrations and adversely impact public health, ecosystem integrity, and agricultural yields. Coal mining processes also have environmental impacts including GHG emissions (Aguirre-Villegas & Benson, 2017). Additionally, fossil fuel plants in Southeast Asia are vulnerable to climate change. Because thermal power plants usually use water for cooling, changes in water resources and water temperature in Southeast Asia due to climate change may constrain future electricity generation from coal plants and their use of water for cooling may add to adverse impacts to river ecosystems (Wang et al., 2019). Hydroelectric power plants are not entirely climate neutral either. Reservoirs behind hydroelectric dams release GHGs including carbon dioxide and methane as buried vegetation decomposes (Fearnside & Pueyo, 2012). In addition, hydroelectric dams themselves transform river ecosystems and decrease river fisheries. This is often detrimental to local communities, local food supplies as well as to biodiversity (Aung et al., 2020; Fearnside, 2016). Thus, integrating renewable energy sources such as wind, solar, and geothermal energy into the electricity system brings multiple co-benefits in addition to mitigation of CO₂ emissions, including air quality, water and health benefits as well as climate resilience.

5. Conclusions

As developed economies transition away from coal-fired power plants, fossil fuel power fleets, especially coal power fleets, continue to expand in developing countries. In this paper, we analyze Southeast Asia's power generation pipeline, that is, power plants that were operational, under construction, and planned, as of mid-2020. We find that fossil fuel and hydroelectric power has dominated the region's power capacity and generation mix. Development as of 2020 indicates that fossil fuel and hydroelectric power will continue to play a dominant role. Power plants that were under construction and planned in 2020 in Southeast Asia will double the region's coal, gas, and hydroelectric power generation capacity from 2019 to 2029. In 2019, Southeast Asian countries had 84 GW of coal and 77 GW of gas power generation capacity in operation. Power plants that were under construction and planned in 2020 will add an additional 100 GW of coal and 60 GW of gas power. Fifty-one gigawatts of hydroelectric power were in operation in 2020 and 52 GW were under construction and planned. In contrast, non-hydro renewables in Southeast Asia remain a tiny portion of the region's power capacity mix (21 GW and 7.4% in 2019) and even less of its power generation mix.

We find that Southeast Asia's power generation pipeline as of 2020 has important implications for both global climate and regional electricity supply. The fossil fuel dominated power generation pipeline will dramatically increase the region's power sector CO₂ emissions in the coming decades, even without considering new fossil fuel plants that may be initiated after 2020. Furthermore, because fossil fuel power plants in Southeast Asia were mostly built after 2000 and are therefore young fleets, they will commit large CO₂ emissions through 2060 if no measures are taken for early retirement of these plants. Coal, gas, and oil power plants that were operating in 2020 have emitted 9 Gt of CO₂ through 2019 and will emit another 18 Gt of CO₂ if they operate under historical capacity factors and emission intensities for 40 years. Fossil fuel infrastructure which was under construction and planned in 2020 will further double total committed CO₂ emissions.

Regionally, we show that projected electricity supply from the power generation pipeline in Indonesia, Vietnam, and the Philippines will greatly exceed these countries' projected electricity demand between 2020 and 2030. Such electricity “oversupply” will lead to underutilization of fossil fuel plants, resulting in stranded fossil fuel power assets, will crowd out renewable energy deployment, or both. We show that it will be years in the future before the electricity demand in these three countries catches up with the great number of fossil fuel power plants that were under construction and planned as of 2020. At the same time, the declining costs of renewable energy technologies imply that renewably generated power may soon become cheaper than fossil fuel power generation in Southeast Asia thus potentially leaving relatively new fossil fuel plants as stranded assets. Therefore, when Southeast Asia plans its power sector development, it should consider both local and global climate risks as well as regional economic and financial risks, of locking into a power sector that is heavily reliant on fossil fuel infrastructure. In the future, with the assistance of the international community, the region is likely to move to more ambitious decarbonization measures. This would reduce CO₂ emissions and climate impacts from projections in this paper. However, the financial risks from stranded fossil fuel power assets will be amplified if current fossil fuel infrastructure development continues and power plants later have to be decommissioned prematurely. Therefore, a rapid change in power sector planning toward more renewable energy would be advantageous to Southeast Asian countries' financial and climate futures.

Data Availability Statement

Compiled data for this research can be found in the Supporting Materials. Original data from the Global Coal Plant Tracker is available at <https://globalenergymonitor.org/projects/global-coal-plant-tracker/tracker/>. Original data from World Electric Power Plant and Bloomberg New Energy Finance can be accessed via subscriptions to these two databases.

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