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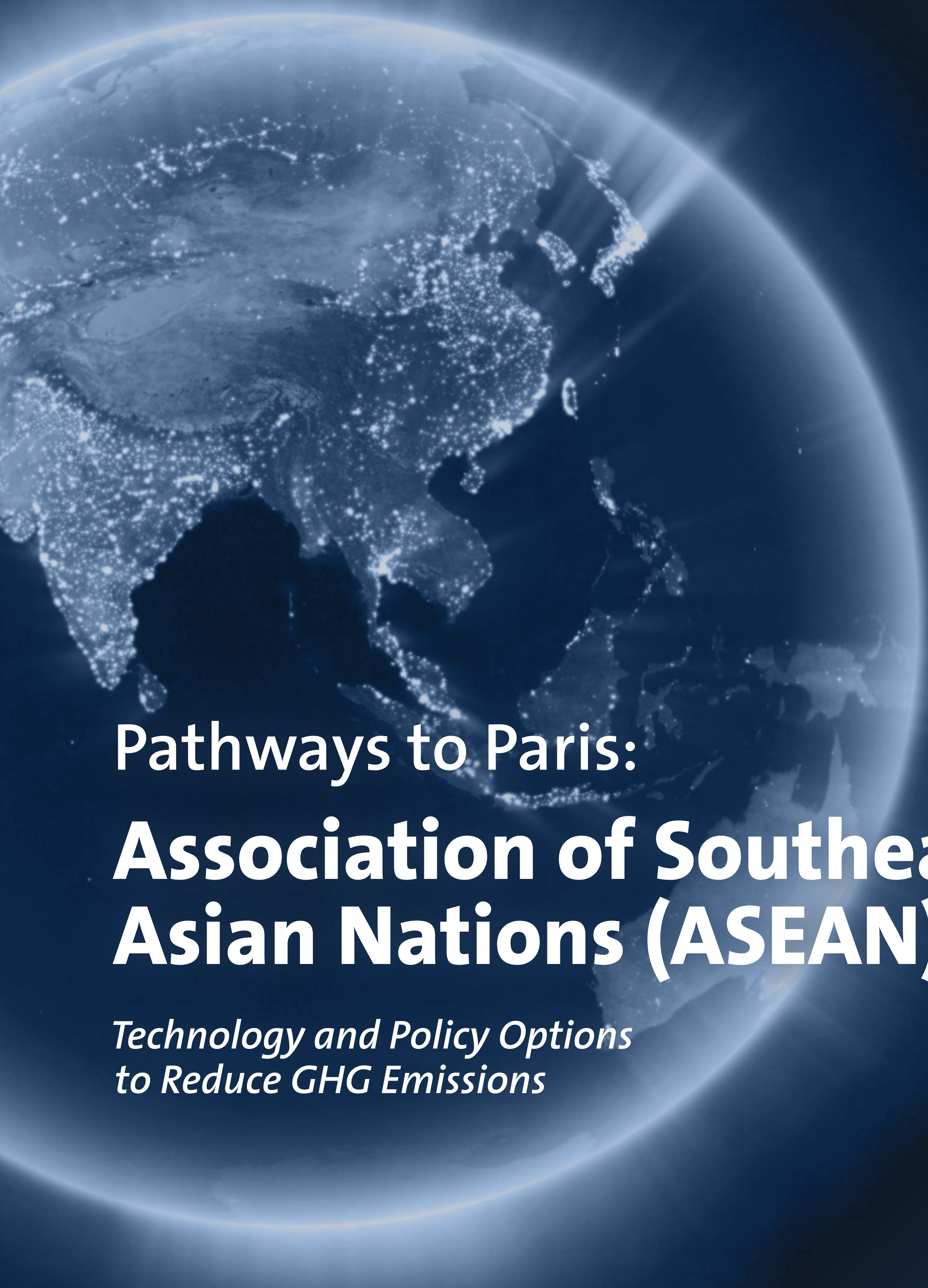

Pathways to Paris:

Association of Southeast Asian Nations (ASEAN)

Technology and Policy Options to Reduce GHG Emissions

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Main Takeaways

- For the Paris Agreement process, the Association of Southeast Asian Nations (ASEAN) countries pledge to reduce their emissions through 2030 and introduce numerous policies to fulfill their pledges. This report offers a discussion of policy instruments and technologies in the energy sector that can assist ASEAN countries in achieving their emission mitigation targets.
- The ASEAN countries face the challenge of reducing GHG emissions while at the same time expanding energy supply to meet the needs of their rapidly developing economies. In aggregate the ASEAN region is making good progress towards its Paris goals but still requires additional action to sufficiently decrease emissions from its current trajectory.
- Under the unconditional pledges, the ASEAN region faces an emissions gap (i.e., the needed reduction to meet the Paris pledges) of around 400 $MtCO_2e$, which indicates that the ASEAN region will have to reduce emissions by 11% by 2030 relative to its current trajectory. Under the conditional (i.e., subject to more ambitious global efforts and technology and financial transfers) pledges, the emissions gap is about 900 $MtCO_2e$, which indicates a needed reduction of 24% by 2030.
- Individually, while some countries are projected to be close to or to even over-achieve their goals for 2030, others need substantial additional efforts. However, there are many policy and technology options to reduce the emissions gap.
- Carbon pricing through taxes or cap-and-trade systems tends to be the most cost-effective option but can be politically challenging to implement. Other policy instruments are therefore needed to promote clean technology (e.g., support to natural gas infrastructure development for countries with large coal use and renewable energy auctions for all ASEAN countries).
- While wind and solar generation provide attractive options for lowering emissions, a switch from coal to natural gas promotes lower-carbon power generation and enables higher penetration of intermittent renewables by serving as backup capacity.
- Our country-specific analysis for Indonesia and Vietnam shows that emission reduction goals are achievable at a manageable cost. For an economy-wide policy, the GDP cost of meeting unconditional pledges in Indonesia and Vietnam is only 0.03% and 0.008%, respectively, relative to GDP in a business-as-usual scenario in 2030.
- Our assessment is unique in providing a gap analysis that consistently covers all ASEAN countries. We provide all input data and tools used in our analysis in an open source format. We hope the open source format will enhance the capacity of ASEAN economies to analyze their pathways to meeting their emission mitigation goals.

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Executive Summary

Context

The world is facing a serious threat from global climate change. In the Paris Agreement, 195 nations have agreed to national greenhouse gas (GHG) emission reductions as a first step toward limiting the global temperature rise to less than 2 degrees Celsius (C) relative to the pre-industrial temperature. Reaching this goal will require a transformation of the global energy system over several decades. The Association of Southeast Asian Nations (ASEAN) countries face the challenge of reducing GHG emissions while at the same time expanding energy supply to meet the needs of their rapidly developing economies. To help them address this challenge, we use a variety of analytical tools—including country-specific, economy-wide models for selected countries—to understand the ASEAN countries' emissions trajectory in both business-as-usual and climate policy scenarios. We also offer a discussion of policy instruments and technologies in the energy sector that can assist ASEAN countries in achieving their emission mitigation targets. This assessment is enhanced by collaboration with representatives of the ASEAN Centre for Energy (ACE). By maintaining an open dialogue on the data and policies incorporated in our projections and by providing all input data and tools used in our analysis in an open source format, we hope to enhance the capacity of ASEAN economies to analyze their pathways to meeting their energy, electrification, and emissions goals.

Limiting global temperature rise to 2 degrees Celsius will require a transformation of the global energy system.

The ASEAN region is an important contributor to global development. In 2015, its population accounted for about 9% of the global population and about 6% of global gross domestic product (GDP) measured at purchasing power parity. In terms of GHG emissions from energy, industry, transportation, agriculture and final consumption (i.e., all sources excluding land use), the ASEAN region's global share in 2010 was about 5%. While eventually emission reductions will need to come from all sectors of the economy, the energy sector offers a significant opportunity to obtain reductions using available technology and policy solutions at a relatively low cost.

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The ASEAN region is projected to have high growth in energy demand—nearly a 100% increase in total primary energy consumption from 2015 to 2030—due to its growing population and economy. Moving to lower-carbon or no-carbon energy (e.g., natural gas, wind, and solar) today will ease the task of reducing GHG emissions in the future.

In the Paris Agreement process, each country determines its own contribution to reduce GHG emissions to mitigate climate change. There is no mechanism to force a country to take on a certain target. Countries are free to choose the stringency of their emission mitigation targets and they may or may not specify the mechanisms to achieve the targets. Countries' pledges (called Nationally Determined Contributions, or NDCs) have various types of targets, such as (1) a reduction in emissions relative to a business-as-usual (BAU) projection, (2) a reduction in emissions relative to some historic year, (3) a reduction in emissions intensity (i.e., the ratio of emissions to GDP), (4) a targeted level or percentage of renewable energy, (5) a reduction in deforestation or an increase in a forest cover of a country, and (6) sector-specific targets such as efficiency improvements. Many countries also provide two stringencies of emission mitigation targets in their NDCs: unconditional (i.e., what a country is planning to do regardless of actions by other countries) and conditional (i.e., unconditional targets plus additional mitigation actions by a country if specific conditions are satisfied, such as a global climate accord, financial assistance, or technology transfers).

Emissions Pathways

This report provides a projection of the ASEAN countries' future emissions trajectory and maps their NDC targets relative to their historic and estimated future emissions. In 2030, the estimated ASEAN Baseline (No Climate Policy) scenario emissions are 3,679 million tonnes of CO_2-equivalent ($MtCO_2e$), and the unconditional emissions target is 3,265 $MtCO_2e$. Consequently, the emissions gap (the volume of reductions to be achieved under a specific target) is 415 $MtCO_2e$, which indicates that, in aggregate, the ASEAN region will have to reduce its emissions by 11% relative to the Baseline scenario to meet its countries' unconditional NDC pledges. Under the conditional emissions target (2,781 $MtCO_2e$), the emissions gap is 899 $MtCO_2e$, which indicates a needed reduction of 24% relative to the Baseline scenario emissions.

Investments in generation from natural gas or in wind and solar in power generation would pave the way for more aggressive emission reductions in the future.

Achievement of NDC goals will be affected by the type of power generation added in each country. For example, investments in coal power plants (without carbon capture and storage, CCS) would lock-in substantial carbon emissions associated with coal use while investments in generation from natural gas—which has a lower carbon intensity than coal—or investments in wind and solar with zero carbon emissions in power generation would pave the way for more aggressive emission reductions in the future. At the same time, coal power in many countries is the cheapest and most reliable energy option, and therefore an attractive path to expand access to energy.

High efficiency, low emission (HELE) coal plants provide an option for lower carbon emissions and significantly reduced (to the level of natural gas plants) emissions of sulphur dioxide (SO_2), nitrogen oxides (NOx) and particular matter (PM). However, if carbon emission reduction goals after 2030 are substantially increased in the ASEAN countries, then further reduction of carbon emissions would require CCS. The current progress on CCS development is rather slow (with only a few power plants at a commercial scale) and the ultimate fate of coal will depend on the cost of investing in CCS versus abandoning or converting the generating assets.

Policy Options

Policy frameworks are the key to determine a nation's ability to incentivize the deployment of new technologies, attract private capital, internalize externalities (such as the health effects of air pollution), modernize electricity transmission and distribution, and expand access to energy. These policies can range from broader policies like energy price reforms and energy subsidy reduction to technology-specific policies like renewable portfolio standards, feed-in tariffs and renewable energy auctions. Carbon pricing through taxes or quantity controls with tradeable units both leave the allocation of resources to the market and can thereby equalize abatement costs across all covered entities, avoiding technology-picking and offering superior cost-effectiveness over alternative instruments.

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Other types of instruments—such as price support measures and fiscal subsidies—can be successful in building coalitions of support, and have also been confirmed through opinion surveys to be more popular with the public. Weak administrative capacities, legal challenges, and unclear mandates can undermine or delay the practical implementation of the instruments which promise to be the most effective and efficient in theory, as shown in the operation of complex policy instruments such as an emissions trading scheme (ETS; see case study of the European Union ETS in Section 7.3.1). Likewise, the legal frameworks protecting foreign and domestic investors in, or owners of, low-carbon technology assets and infrastructure can be a greater determinant of the success of renewable energy or energy efficiency support measures than the design and implementation of those measures themselves.

Currently, electricity market designs are again facing substantial pressure to transform. The emergence of disruptive technologies, such as distributed energy resources and digitalization, coupled with ever more stringent environmental policy requirements, are fundamentally changing the landscape in which energy markets operate. When considering their policy framework, ASEAN economies need to begin by thinking about how the design of their electricity market will advance their energy security and climate goals. Design of electricity markets, for instance, needs to facilitate the integration of distributed or centralized resources contributing to the efficient provision of electricity services and attainment of other public objectives.

To successfully integrate growing shares of variable renewable energy sources, electricity market design has to ensure proper incentives for adequate reserve and balancing capacity through capacity markets or other mechanisms. A comprehensive and efficient system of market-determined prices and regulated charges needs to reflect energy-related services (such as electric energy, operating reserves, firm capacity, and ramp-up capability) and network-related services (such as network connection, voltage control, power quality, network constraint management, and energy loss reduction). Market interconnections with other countries/regions provide the potential to make more efficient choices, better integrate intermittent and distributed resources, and enhance system reliability and resilience.

Another important feature of many electricity markets with substantial repercussions for climate change mitigation is price supports for conventional energy, such as fossil fuel subsidies. The reduction and eventual elimination of energy subsidies leads to the correction or removal of distortions in costs and prices that inform the decisions of producers, investors, and consumers. In many cases, energy subsidies prolong the life of older technologies and energy-intensive methods of production while often undermining the credit worthiness of utilities. Subsidy removal reduces the strain on fiscal resources and potentially leads to their improved allocation.

The ASEAN countries list in their NDCs numerous plans, policies, and strategies as their means to achieve their emissions reduction goals. Because the ASEAN countries represent a wide variety of economies in terms of their level of development and institutional capacity, their choice of policy instruments for GHG emission mitigation depends on administrative and technical capacities to introduce and enforce a particular policy, political support for the desired stringency of emission reductions, and willingness to accept the associated economic cost. Currently, the climate and energy policy portfolios of most ASEAN countries are dominated by a patchwork of energy savings measures and targeted support for renewable energy, embedded in broader—and in many cases aspirational—mitigation strategies. While these policies have shown some positive effects, they are not always cost-effective, nor do they yet have the scalability to set in motion a broad transition towards a lower-carbon future. Our analysis shows that ASEAN nations have the opportunity to achieve greater GHG reduction gains, at relatively low cost, through better policy coordination, stronger policy signals, and the introduction of new technologies.

No ASEAN member nation has implemented a carbon price to date, but interest in this highly cost-effective and scalable policy option is growing, with at least one ASEAN country (Singapore) already planning adoption of a carbon tax in the near term. For the ASEAN countries with more advanced administrative and technical capacities, we therefore recommend carbon pricing through taxes or quantity controls with tradeable emission permits because they offer the greatest economic efficiency benefits. These instruments are particularly suitable for countries with substantial experience with market-based mechanisms and competitive electricity markets. International experience with such markets is extensive (for an overview of experience, see Section 7.3 of the report), and capacity building initiatives and guidance on their design and implementation are readily accessible from a variety of sources, some of which are already active in several ASEAN countries (e.g., the World Bank Partnership for Market Readiness). As deployment of carbon pricing instruments in the region has been halting, it should therefore be a priority of future policy development for economically more advanced ASEAN countries. Singapore's adoption of a legislative basis for introduction of a carbon tax in 2019 will set a useful near term example for neighboring ASEAN countries to study.

For countries that are still in the process of advancing their institutional capacities, we recommend an initial focus on technology-specific policies such as renewable portfolio standards, feed-in tariffs and renewable energy auctions. Feed-in tariffs are already in place in several ASEAN countries—such as Indonesia, Malaysia, and Thailand—and renewable energy auctions are gaining more widespread use. Such support measures can be more successful in building coalitions of support for ambitious climate policies, and also in creating the domestic supply chains and know-how needed for robust markets in clean technology.

At a later stage, however, such targeted support measures should be reviewed and, where political will and institutional capacities allow, gradually phased out as more cost-effective mitigation instruments, such as carbon pricing, are introduced and scaled up. Recent reductions in fossil fuel subsidies across the ASEAN region have shown that political support can be mustered for policy reforms that may increase energy prices. At the same time, thoughtful implementation of policy changes is critical. The political backlash against sudden electricity cost increases due to feed-in tariffs in the Philippines led to the elimination of feed-in tariffs for a majority of renewable energy project types in 2017. The Philippines example shows how politically sensitive energy prices remain and reveals the obstacles governments must overcome to introduce policies affecting energy prices.

Political support can be mustered for policy reforms that may increase energy prices. At the same time, thoughtful implementation of policy changes is critical.

In the medium-term, natural gas offers a viable option for lowering emissions in countries that have substantial share of coal generation (e.g., Indonesia, Malaysia, The Philippines, and Vietnam). To realize the potential of natural gas, policy options include a support to natural gas infrastructure development and loosening or removing price rigidities. An important component of a national gas strategy is allowing more private participation in supply, transportation, and marketing of natural gas, including third-party access to natural gas infrastructure. An early experience by other countries that promote natural gas use (e.g., Mexico, China, and Egypt) illustrates the need for natural gas pricing reforms that reflect the market fundamentals and promote competition, thereby enhancing new supplies that ultimately lower the costs.

To realize the potential of natural gas, policy options include a support to natural gas infrastructure development and loosening or removing price rigidities.

An important component of a national gas strategy is allowing more private participation in supply, transportation, and marketing of natural gas, including third-party access to natural gas infrastructure.

In any country, a policy package with one clear core policy instrument and complementary planning, market and regulatory instruments (which share a common objective with the core instrument) is often critical to secure investment decisions and implement and execute projects. A coherent, targeted policy package performs differently than a combination of various core policy instruments with different objectives. In terms of assembling policy portfolios, this difference should be clearly recognized.

Because different policy objectives require their own policy instruments, we recommend that policies adopted to promote climate mitigation should avoid the simultaneous pursuit of other policy objectives, such as development, labor, or industrial policy goals. Combining policy instruments can lower overall efficiency due to adverse interactions and trade-offs.

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We therefore recommend establishing a clear and transparent policy mix that allows for periodic policy review and adjustments. In many cases, pilot programs (1–2 years) can serve to fine-tune policy design and prepare economic actors for policy compliance; thereafter, however, policies with long time horizons (5 years or more) are recommended to provide planning and investment certainty to market participants. These long-term policies should contribute to overarching mitigation strategies and should be accompanied by robust planning processes to ensure consistency across instruments as well as to establish the supporting institutional and regulatory frameworks.

Substantial progress towards emission mitigation goals can be achieved by modernization of electricity market design and a reduction and eventual elimination of fossil fuel subsidies. Although fossil fuel prices in most ASEAN countries fluctuate based on prices in international markets, they remain regulated and are not fully liberalized (e.g., natural gas in Myanmar and Thailand, gasoline and diesel in Vietnam and Indonesia). As electricity demand is growing rapidly in most ASEAN countries, a reform in electricity subsidies (both for residential use and for certain type of fuels like natural gas) will be a key issue despite the associated political difficulties. Subsidy removal reduces the strain on fiscal resources and potentially leads to their improved allocation. We therefore recommend continuation of recent efforts at subsidy removal (e.g., experiences with removing subsidies for gasoline and diesel in Indonesia and Malaysia, reform of CNG and LPG pricing in Thailand, and changes in electricity pricing in Vietnam), combined with creation of targeted support to low-income consumers.

Technology Options

Numerous technology options are available for GHG emission mitigation. We categorize the most promising options into three clusters. In *Tier I* we include options related to building or retrofitting power plants to provide lower-carbon generation options than the current fleet. The options vary by their capital-intensity, maturity and scale and include the development of wind, solar, natural gas, hydro, geothermal, and waste technologies. Thus, for many ASEAN countries, this tier means moving away from unabated coal-based generation. While wind and solar generation provide better options in terms of lowering carbon emissions, natural gas also has a substantial role both as a fuel with a lower carbon content than coal and as a technology that allows a higher penetration of intermittent renewables by serving as a backup capacity to provide reliability for the electricity system.

In *Tier II* we group the technology options that lead to improved efficiency (more-efficient turbines, digitalization, etc.), both on the production and on the consumption of electric power. The options in *Tier III* relate to technologies that enhance market and network organization (e.g., enabling distributed generation, time-of-the-day pricing, etc.), and include options for improved integration of renewables (e.g., new transmission lines, virtual power plants, microgrids, tools for better citing and forecasting of wind and solar farms to maximize their utilization).

Despite substantial progress in bringing down costs of certain types of low-carbon power generation, the considerable uncertainty about the future costs of different technologies and the challenges for their integration to the system necessitates a flexible approach. We recommend that policy makers incentivize emission reductions from all sources of energy rather than favor any particular technology.

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Most ASEAN nations are at the beginning stage of introducing new technologies for emissions reduction. As countries update their NDCs, this is an opportunity to create frameworks that encourage the adoption of these technologies to improve the efficiency of the power sector and reduce emissions. For example, as wind and solar options become more competitive, they offer a valuable option for emission reduction. The ASEAN countries are still at low levels of penetration of intermittent renewables, and therefore, their integration into the power system is currently relatively simple. ASEAN nations can learn from others how to avoid the challenges of higher levels of renewables penetration by directing policy makers, regulators, market and network operators, utilities, and other players to plan and prepare for the integration of higher shares of non-dispatchable technologies such as wind and solar. The experience of countries with large shares of renewables (e.g., Germany, Denmark, Belgium, and Portugal) provides valuable guidance for understanding challenges and opportunities of intermittent generation sources.

While coal power is the cheapest and most reliable energy option in many ASEAN countries, natural gas provides a viable alternative in order to reduce GHG emissions and local air pollutants. Some ASEAN nations are only beginning to introduce natural gas as a fuel choice in their economies by developing access to LNG, piped gas, or domestic supply. We have seen this trend grow in China, Japan, Korea, and Taiwan, as well as more recently in Malaysia and Pakistan. However, because future emission reduction targets (for the period beyond the current Paris pledges) are likely to be more aggressive, we also recommend exploring options for nuclear and CCS technologies, keeping in mind that these capital-intensive projects require longer planning timelines and extensive government support.

We also recommend a wider use of technologies that enable energy efficiency improvements, both in the construction of more efficient power plants and through the use of digital technology to improve existing supply- and demand-side processes. Decision-makers should monitor the latest advances in technologies that enhance market and network organization (e.g., enabling distributed generation, time-of-the-day pricing, etc.) and consider options for the improved integration of renewables. These technology options are highly under-utilized in the ASEAN context and provide opportunities for regulators and policymakers.

We emphasize that other technologies may become more attractive in the future. Possible options include energy storage as well as the production of hydrogen with renewable power and its consequent use for energy needs. Therefore, we recommend monitoring technological progress and adjusting the options under consideration as new technologies become more economically feasible. At the same time, decision makers should be able to perform an objective evaluation of the prospects of the advanced technologies rather than rely on potentially over-optimistic promises of sellers of new technological options.

The scale of the required transformation in the ASEAN region as a whole can be illustrated with a hypothetical example of removing coal-based generation from the electricity mix. While we do not advocate for a complete replacement of coal-based generation in a short period of time, the impact of technology choice can be dramatized by our illustrative example showing the magnitude of a potential change. Depending on the natural gas capacity factor, replacing all coal-based generation with natural gas by 2030 corresponds to about 1,000–1,500 new 100MW natural gas turbines in the ASEAN countries. Depending on the wind generation capacity factor, replacing all coal-based generation with 4MW wind turbines corresponds to about 30,000–45,000 new wind turbines in the ASEAN region. Furthermore, replacing all coal generation with wind displaces 764 $MtCO_2$, which falls short of achieving the ASEAN region's conditional targets (a needed reduction of 899 $MtCO_2e$) but is sufficient to achieve its unconditional targets (a needed reduction of 415 $MtCO_2e$). These illustrative estimates convey that, while in many cases actions targeting only the power generation sector will not be sufficient for meeting a nation's Paris Agreement goals, major shifts in choice of generating technology move the ASEAN countries significantly toward their emission reduction goals. Mitigation action most likely will employ a set of different options in different sectors of the economy rather than achieve all emission reductions exclusively in the power generation sector through replacing or improving an entire generation fleet.

Deep Dive: Indonesia and Vietnam

This report also provides additional focus on Indonesia and Vietnam through MIT-developed economy-wide models. Our detailed analysis leads us to the conclusion that reductions in GHG emissions to meet their respective NDC unconditional targets are achievable at a manageable cost. For an economy-wide policy, the GDP cost in Indonesia and Vietnam is only 0.03% and 0.008%, respectively, relative to GDP in the BAU (No Policy) scenario in 2030. Deviations from this most efficient policy (i.e., moving from economy-wide coverage to sector specific policies) increase the costs. For example, an ETS applied to only the energy-intensive industries induces "emissions leakage"—an increase in activity and GHG emissions in the uncovered sectors—and thus requires a higher carbon price (roughly 3 times larger in Indonesia and 3 to 7 times larger in Vietnam) than would an economy-wide ETS.

The most costly simulated impacts arise from meeting conditional targets using an ETS with coverage of only energy-intensive industries. In Indonesia, this scenario decreases electricity generation in 2030 relative to the BAU by nearly 25% while in Vietnam electricity generation decreases 27.6%. The key insight from these simulations is that the sectoral coverage of climate policy should be a broad as possible. This can be achieved by either including as many sectors as possible in the ETS, or linking non-ETS sectors to included sectors by allowing domestic offset credits to be surrendered in lieu of ETS permits (see the case studies on the European Union ETS and the Western Climate Intiative in sections 7.3.1 and 7.3.3).

Digitalization measures can support the dual-pursuit of development and climate policy goals. We estimate up to a $1.8 billion (0.1%) increase in GDP and 14.6 TWh (2.6%) increase in electricity generation in Indonesia, and up to a $1.7 billion (0.3%) increase in GDP and 8.7 TWh (2.4%) increase in generation in Vietnam, in 2030 relative to scenarios without the use of digitalization technologies.

Policy Recommendations for Indonesia

We recommend further strengthening of Indonesia's existing policy portfolio, including more ambitious targets for low-carbon generation and coordination of policies in the power sector with policies in the other sectors of the Indonesian economy. Such coordination calls for better inter-agency cooperation. A newly formed Directorate General of Climate Change, operating under the auspices of the Ministry of Environment and Forestry, can work alongside the Ministry of National Development Planning to implement the National Action Plan for Greenhouse Gas Reduction, a presidential decree of 2011, which sets out a cross-sectoral framework for Indonesia's climate strategy.

Currently, emissions from rainforest and peatland loss still dominate the country's emissions profile. Going forward, however, emissions growth will shift to the energy sectors, where robust economic growth has also resulted in a steep increase in energy demand, seeing electricity demand, for instance, almost double over the last decade.

Planned expansion of coal-fired electricity generation, in particular, will pose a substantial challenge for achievement of Indonesia's pledged mitigation targets, although it aligns with the strategic objective of achieving greater energy security. For future policy design, this poses a twofold challenge. To be effective at curbing emissions, Indonesia's instrument portfolio will have to both address the substantial emissions from land use, land use change and forestry, and require shifting the further expansion of electricity generation towards Indonesia's abundant domestic renewable resources.

Timing is also a critical factor: as Indonesia progresses with its planned expansion of electricity generation capacity, it faces a considerable risk of long-term carbon lock-in. As it implements the Electricity Supply Business Plan for 2016–2025, which anticipates the addition of 80 GW in generating capacity over the course of a decade, any new fossil-fueled generation capacity will continue to emit over the considerable useful economic life of these assets.

Mitigation actions in seven key areas outlined in the government plans should be enhanced: sustainable peat land management; reducing the deforestation and land degradation rate; developing carbon sequestration projects in forestry and agriculture; promoting energy efficiency; developing alternative and renewable energy sources; reducing solid and liquid waste; and shifting to low-emission transportation mode.

In the area of land use, land use change, and deforestation, cooperation with international donors has resulted in a temporary moratorium on new forestry licenses and peatland development. A "One Map Initiative" aimed at developing a unified forestry mapping system has the potential to greatly increase transparency on emissions from deforestation. In the transportation sector, whose emissions are likewise growing at a rapid pace, several pilot and demonstration projects seek to expand use of public transportation and improve urban transportation infrastructure.

As Indonesia considers options to further strengthen its existing policy portfolio, it has a unique opportunity to accelerate the shift from continued growth of fossil fuels in electricity generation, heating, and transport to renewable energy sources. While Indonesia enjoys abundant domestic reserves of hard and brown coal, it is also richly endowed with untapped renewable energy potential, especially in biomass, geothermal, hydropower, solar, and tidal energy. Not only will substitution of fossil resources with renewable energy be essential to achieve mitigation objectives, it will also mobilize important additional benefits, such as reduced air and water pollution as well as associated health impacts.

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A stronger policy portfolio might be translated into more ambitious targets for renewable energy deployment in Indonesia's national energy strategy. Rapidly falling technology costs make a much more aggressive expansion trajectory for renewable energy economically viable. A transition away from the established fossil fuel sector will face resistance and necessitate careful planning to avoid social hardship, but opportunities for strong growth, employment and innovation also exist along the renewable energy supply chain. Overall, the net benefits of a transition will outweigh costs. But accelerating growth in renewable energy use will require coordinated action along multiple levels.

Renewable energy auctions are a proven instrument to cost-effectively scale up growth of renewable energy while retaining control over the pace and cost of the transition (for an overview of international experience with renewable energy auctions, see Section 7.1.2 of the report). Increased reliance on renewable energy auctions needs to be complemented by forward-looking infrastructure planning to ensure grid integration of new and variable generation capacities, including in remote areas with small, isolated grids. International cooperation and policy learning can help build technical capacity and inform future reforms of Indonesia's electricity market with a view to better managing an evolving electricity mix.

Emissions are also rapidly growing in the transport and residential sectors. Carefully managed to minimize land use impacts, expanded use of biofuels can play a considerable role in reducing the emissions intensity of these sectors. Continued use of targeted energy efficiency measures (e.g., Energy Management Regulation 14/2012 of the Indonesia's Ministry of Energy and Mineral Resources requires energy efficiency plans and periodic energy audits for entities consuming more that 6000 tonnes of oil equivalent per year) offer a useful way to curb emissions growth, but can suffer from low cost-effectiveness and have unintended effects. Over time, Indonesia should therefore consider instituting a price on carbon to leverage this policy's ability to scale up abatement at least cost across all sectors, create a more even playing field between carbon-intensive and renewable technologies, and potentially leverage carbon finance from third countries through offset projects or international linkage of carbon pricing policies. Indonesia already has a good track record of international carbon market participation under the Clean Development Mechanism (CDM) of the Kyoto Protocol and, more recently, the bilateral Joint Crediting Mechanism (JCM) with Japan.

Rather than relying on public expenditures, as many current measures do, carbon pricing could also be a source of much-needed revenue for public budgets. It is also vitally important that Indonesia continue initial efforts under the current administration to reform fossil fuel subsidies, which continue to bind a significant share of the public budget. Although a weakening currency and rising fossil fuel prices make it harder to sustain the recent pace of reform, further subsidy reductions will likewise reduce the strain on public budgets. Combined with carbon pricing revenue, this will allow Indonesia to allocate greater financial resources for strategic investment in innovation and infrastructure development, which will be key for further growth of renewable energy in electricity generation and electrification of transport.

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More generally, institutional and regulatory challenges, including fragmented governance structures involving a large number of government actors, have been identified as barriers to effective translation of national commitments to the regional and local level). While the creation of the Directorate General of Climate Change marks a useful first step, further integration and mainstreaming of climate policy priorities across all levels of government is recommended.

Policy Recommendations for Vietnam

Our policy recommendations for Vietnam focus on bringing down its energy intensity, which is the highest among major East Asian economies, and shifting future growth in electricity generation capacity to renewables and natural gas. Strengthening and better enforcement of existing policies on energy efficiency and renewable energy, continued energy price reform and restructuring of the power sector, and, prospectively, introduction of a carbon price are all suited to advance decarbonization of the power sector.

Emissions growth in Vietnam is primarily driven by the energy sector. Despite an already high electrification rate, electricity demand is expected to quadruple from 2010 to 2030 driven by industrial demand growth. Much of this electricity generation is projected to come from coal, of which the country possesses ample domestic reserves. Agriculture, while still an important source of emissions, is declining in relative importance, and industry and waste each contribute only a small share of the country's emissions.

Policy recommendations therefore focus on ensuring that new electricity generation capacity is based on renewable energy and natural gas rather than coal and, especially in the short term, curbing energy demand growth as a way to buy time for fuel switching in the electricity sector. Opportunities for both are ample, with significant low cost potential documented for energy efficiency improvements in households and industry, and attractive conditions for solar and on- and offshore wind energy deployment. Ongoing construction of LNG import terminals will also allow increased use of natural gas in electricity generation.

Vietnam already has a robust foundation for climate policy in place. As a country with centralized, top-down decision-making structures, Vietnam relies on 5-and 10-year planning cycles. Three strategic frameworks guide its policies on climate change mitigation: a National Climate Change Strategy, a National Green Growth Strategy, and a National Strategy on Environment Protection. In 2012, Vietnam adopted a National Action Plan on Climate Change for the period 2012–2020, which sets out objectives and a large number of specific programmes and projects.

Aside from shortfalls in the effective implementation and enforcement of existing rules, an important challenge has been that centrally determined electricity prices are fixed at low, albeit progressive, levels. Although the government has commendably announced a phase-out of fossil fuel subsidies by 2020, the block electricity tariffs set by the government are not fully reflective of marginal generation costs and therefore amount to an implicit price support. Not only does this reduce the incentive for energy conservation, it also provides insufficient cost-recovery and return on investment in the power sector.

In 2015, Vietnam adopted a Renewable Energy Strategy for 2030, with targets that represent a declining share of renewables in electricity generation to reflect the faster expansion anticipated for generation from coal and natural gas. This Strategy is largely consistent with the latest iteration of the National Power Development Plan (2016–2030), which envisions the addition of 77 new coal-fired power generation plants by 2030. Several support mechanisms incentivize electricity generation from renewable sources, including feed-in tariffs, net metering, and compensation based on avoided cost, complemented by grid codes, standardized power purchase agreements, and incentives related to corporate income tax, import duties, and land use.

Although these policies have helped open the electricity sector for private investment, it continues to be dominated by a state-owned enterprise, Electricity Vietnam (EVN). Private investors, which already face greater financial risk and capital constraints than the state-owned EVN, also struggle with fixed electricity rates that are too low to cover capital costs for new investments or recover operating costs for existing power generation. Prices for coal—which is mined by another state-owned enterprise, the Vietnamese National Coal and Mineral Industries Group—are also regulated by the government and, although linked to the international market, are considered low.

Taken together, low prices for electricity and coal, modest and unevenly enforced incentives, and an electricity market that creates barriers to private sector entry dampen prospects for energy efficiency improvements and rapid growth in renewable energy generation. With earlier plans to develop nuclear power suspended for reasons of cost, and remaining hydroelectric potential at risk due to climate change, decarbonization of the Vietnamese power sector will rely on natural gas and, increasingly, solar, wind and biomass. Aside from reduced externalities, the latter three also offer the benefit of improved energy security through independence from energy imports. Existing policies provide a solid basis for their promotion, but the effectiveness of this policy framework could be enhanced with more ambitious targets and strengthened institutional capacities to ensure rigorous enforcement.

Importantly, continued restructuring of the power sector can be an important enabler of scaled-up investment in clean energy technologies. As the ongoing power sector reforms spur a transition from an electricity market design with state monopolies and centrally controlled prices to a competitive electricity market in which market dynamics determine prices, renewable energy sources, natural gas, and energy efficiency investments will become more cost competitive. Greater competition will also reduce emissions through operational and efficiency gains, as inefficient and emissions intensive coal fired plants see less frequent dispatch or exit the market.

Leveraging the signaling effect of prices that more accurately reflect underlying cost also requires thinking about carbon pricing over time. In a competitive electricity market, a carbon price will further strengthen the merit of lower-carbon technologies relative to coal, for instance by promoting fuel switching from coal to gas. Vietnam already announced in 2012 that it would launch a national emissions trading system for carbon covering all major emitting sectors. For the carbon price to be effective, however, continued privatization of state-owned enterprises and deregulation of electricity tariffs will be critical to foster responsiveness to market signals. Ultimately, a carbon price will also help channel private sector finance to low-carbon investments, helping overcome another major barrier for mitigation efforts faced in Vietnam.

Ultimately, a carbon price will also help channel private sector finance to low-carbon investments, helping overcome another major barrier for mitigation efforts faced in Vietnam.

International Experiences

The ASEAN countries can learn from positive and negatives experiences with emission reduction policy mechanisms in other regions of the world. We offer a detailed exploration of the lessons learned worldwide from employing policies to promote renewable energy, such as feed-in tariffs and renewable energy auctions. We also summarize the experience with standards, regulations, and carbon pricing systems in other regions.

While feed-in tariffs were initially a popular instrument to develop wind and solar projects, renewable energy auctions have become a more established tool in the portfolio of clean energy support instruments. By fostering strong competition, they have contributed to low project cost bids. Time will tell whether these bids come at the expense of low realization rates. Concerns about the financial feasibility of some projects, difficulties in securing financing, and issues with access to transmission infrastructure help explain relatively low realization rates for certain projects in Brazil, Mexico and Argentina. At this point, it is too early to tell if the experience of these initial projects is indicative of future challenges or if the realization rates will be improved with more maturity in this policy instrument. The example of auctions illustrates the value of studying international policy experiences.

Overall, we recommend that ASEAN policy makers carefully survey the lessons learned in other regions with emission reduction policies, and apply best practices by tailoring these policies to local conditions. But there are also some overarching recommendations we can infer from international experience. Given the emissions gap identified in this report, ASEAN countries will invariably have to strengthen existing and adopt additional policy instruments to achieve their NDCs. Both

ASEAN countries will invariably have to strengthen existing and adopt additional policy instruments to achieve their NDCs.

practical and theoretical arguments justify adopting a mix of different policies to build capacity, foster policy support, and start the gradual transformation process of the economy.

Already, ASEAN countries have leveraged many of the benefits of a diverse instrument portfolio. At the same time, experience shows that coexistence of multiple policy instruments can result in negative policy interactions, increasing the economic cost of achieving climate targets. By favoring specific technologies, targeted policies may also miss valuable abatement opportunities. Over time, as ASEAN countries strengthen their technical capacities and explore more ambitious goals for future NDC cycles, we therefore recommend they focus on economy-wide carbon pricing as a central pillar of their mitigation strategies and better harmonization of existing policies until they achieve that goal.

1 Introduction

Under the United Nations (UN) Paris Agreement, 195 nations signed-on to limit the rise in average global surface temperatures to less than 2 degrees Celsius (C) above pre-industrial levels (UN, 2015). Reaching this goal will require a transformation of the global energy system over the upcoming decades (MIT Joint Program, 2016). Most of the signatories of the Paris Agreement are refining their Nationally Determined Contributions (NDCs) for the 2018 Facilitative Dialogue that will be held at the 24th session of the Conference of the Parties (COP24) in Katowice, Poland in December 2018. Countries can deploy a wide range of policies to bridge the gap between current emission trajectories and NDC goals, and national strategies for compliance with NDCs are evolving.

The goals of this report are to conduct a gap analysis between emission levels that can be achieved under current policies/practices and national-level NDC targets for the Association of Southeast Asian Nations (ASEAN) block of ten countries (Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam), to identify key challenges to compliance, and to suggest regionally applicable policy and technology solutions, with a focus on the electricity sector. There are several publications that track the progress of reaching the Paris Agreement goals, such as UN Emissions Gap Report (UNEP, 2017) and Climate Action Tracker (climateactiontracker.org). They focus on global results providing information for selected countries.

Our assessment is unique in that the gap analysis consistently covers all ASEAN countries and clearly documents the data and assumptions associated with our calculations of the future emission trajectories (the "Baseline scenario") and 2030 policy targets. Simple spreadsheet-based tools are available (upon request) for every ASEAN country. This available tool provides an opportunity for an independent verification and a sensitivity analysis for the Baseline scenario input assumptions and for further improvement of the assessment.

The ASEAN countries face the challenge of reducing greenhouse gas (GHG) emissions while at the same time expanding energy supply to meet the needs of rapidly developing economies. The ASEAN region is an important contributor to global development (see Figure 1.1). In 2015, its population accounted for 8.6% of the global population (UN, 2017) and 5.6% of global gross domestic product (GDP) measured at purchasing power parity (IMF, 2017). In terms of GHG emissions from energy, industry, transportation, agriculture and final consumption (i.e., all sources excluding land use), the ASEAN region's share in 2010 was 4.5% (IEA, 2016a).

GHG emissions related to land-use, land-use change, and forestry (LULUCF) are substantial for the ASEAN region, but they are known with less certainty than energy and industrial emissions. According to IEA (2016a), the ASEAN region's LULUCF emissions are about 30% of global LULUCF emissions in 2010. Figure 1.2 shows that in 2010 the LULUCF emissions contributed to about 50% of the total GHG emissions in the ASEAN. Activities in the LULUCF sector can provide a way to reduce emissions, either by increasing the removal of GHGs from the atmosphere (e.g., by planting trees), or by reducing emissions (e.g., by reducing deforestation). However, GHGs may be unintentionally released into the atmosphere if a sink is damaged or destroyed through a forest fire or disease (UNFCCC, 2017a).

It is difficult to estimate greenhouse gas removals and emissions resulting from activities of LULUCF (UNFCCC, 2017a) and estimates from different sources, such as the United Nations Food and Agriculture Organization (FAO, 2017) and national communication to the United

Nations Framework on Climate Change (UNFCCC, 2017b) provide a wide range of values for LULUCF emissions in the ASEAN countries. Where applicable, in this report we follow IEA data (IEA, 2016a) because it provides a consistent coverage for 2000–2010 for the ASEAN countries (see Figure 1.3). Data for Lao PDR, which is not reported by the IEA, is sourced from the ASEAN Center for Energy (ACE).

In this report, we focus on non-LULUCF activities and therefore exclude LULUCF emissions from our analysis unless specifically stated otherwise. While eventually emission reductions will need to come from all sectors of economy, the energy sector offers a significant opportunity to use available technology and policy solutions at relatively low cost (IEA, 2015). The ASEAN region is projected to have a high growth in energy demand—nearly a 250% increase in total final energy consumption from 2015 to 2040 (ACE, 2017)—due to an expanding population and economy. One challenge for the ASEAN region is that coal is abundant in the larger countries and a cheap way to meet the growing energy demand; however, moving to lower-carbon energy today will ease the task of reducing GHG emissions in the future.

The rest of the report is organized in the following way. In the next section, we overview the pledges made by the ASEAN countries for the Paris Agreement process. Section 3 provides our projections for ASEAN emissions out to 2030. In Section 4, we discuss technology and policy options to reduce GHG emissions. Section 5 reports country-specific estimates and in Section 6 we provide a detailed analysis of economy-wide impacts for two selected countries: Indonesia and Vietnam. Section 7 offers an overview of experience with policy instruments to reduce GHG emissions in different parts of the world with the focus on lessons learned.

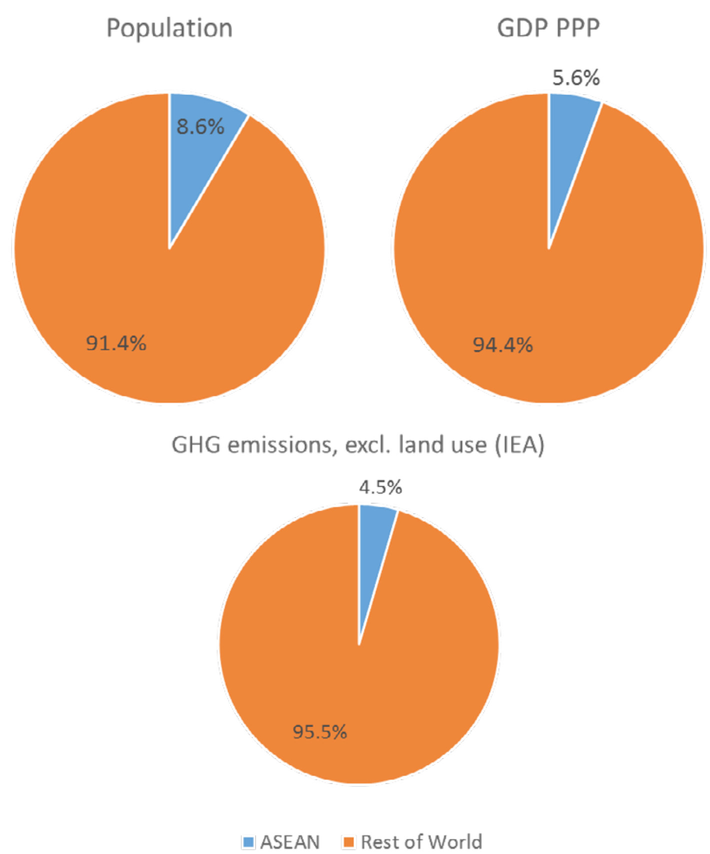

Figure 1.1. ASEAN's shares in global population, GDP, and GHG emissions

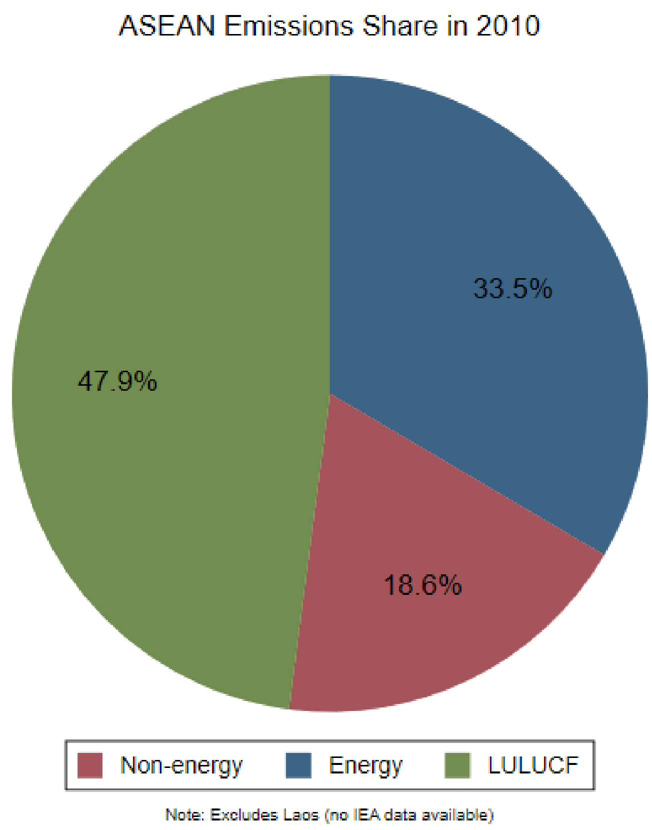

Figure 1.2. ASEAN's GHG emissions in 2010 by sector (energy, non-energy, and LULUCF)

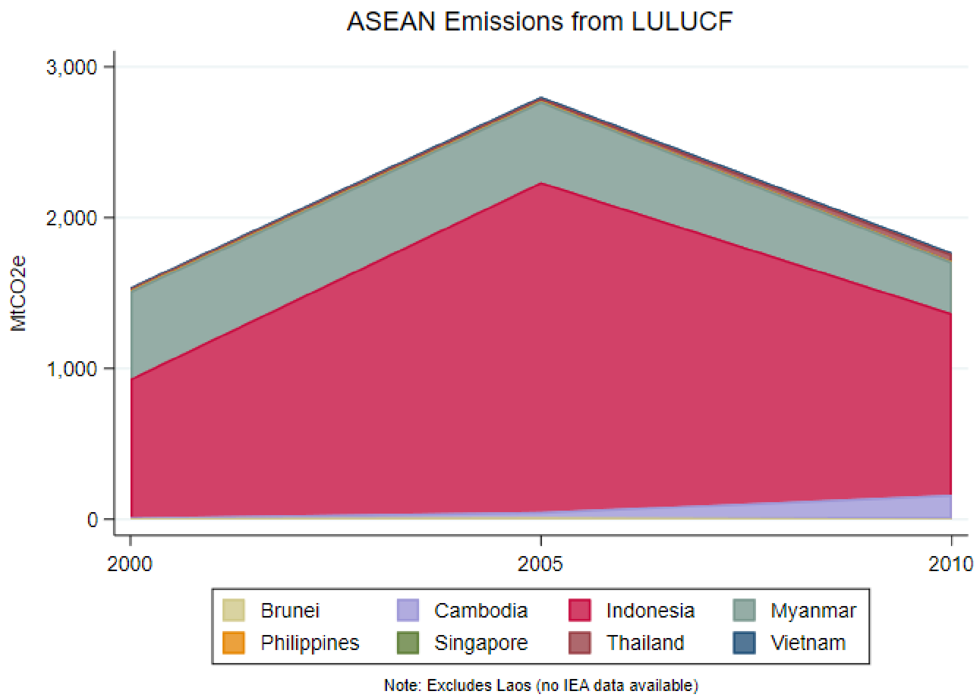

Figure 1.3. ASEAN's LULUCF emissions for 2000, 2005, and 2010.

2 Pledges of the ASEAN Countries for the Paris Agreement Process

Main Takeaways

- Driven by a growth in energy-related emissions, GHG emissions in the ASEAN region are projected to increase from about 2,200 $MtCO_2e$ in 2015 to about 3,700 $MtCO_2e$ in 2030.
- Despite the projected increase in the level of emissions, the ASEAN countries are committed to a substantial reduction in growth of their GHG emissions relative to the Baseline (No Policy) case.
- Many countries provide two types of targets in their NDCs for emission mitigation: unconditional (i.e., what a country is planning to do regardless of actions by other countries) and conditional (i.e., unconditional targets plus additional mitigation actions by a country if specific conditions are satisfied, such as a global climate accord, financial assistance, technology transfers, or other conditions).
- In 2030, the estimated unconditional emissions target is about 3,300 $MtCO_2e$. Consequently, the emissions gap is around 400 $MtCO_2e$, which indicates that, in aggregate, the ASEAN region will have to reduce their emissions by 11% relative to the Baseline scenario. Under the conditional emissions target (about 2,800 $MtCO_2e$), the emissions gap is about 900 $MtCO_2e$, which indicates a needed reduction of 24% relative to the Baseline scenario emissions.
- ASEAN countries are on different trajectories relative to their emission targets. For 2030 some countries are projected to be close to their goals or even to over-achieve them, while some countries still need substantial additional efforts to narrow the emissions gap.

In the Paris Agreement process, each country determines its own contribution to reduce GHG emissions to mitigate climate change. There is no mechanism to force a country to take on a certain target. Countries are free to choose the stringency of their emission mitigation targets and they may or may not specify the mechanisms to achieve the targets. Countries' pledges have various types of targets, such as (1) a reduction in emissions relative to some business-as-usual (BAU) projection, (2) a reduction in emissions relative to some historic year, (3) a reduction in energy intensity (i.e., the ratio of emissions to GDP), (3) targeting a certain level or a percentage of renewable energy, (4) a reduction in deforestation or an increase in a forest cover of a country, and (5) sector-specific targets such as efficiency improvements.

Many countries provide two types of targets in their NDCs for emission mitigation: unconditional (i.e., what a country is planning to do regardless of actions by other countries) and conditional (i.e., unconditional targets plus additional mitigation actions by a country if specific conditions are satisfied, such as a global climate accord, financial assistance, technology transfers, or other conditions). In many cases, there is substantial ambiguity about converting some targets (e.g., a renewable electricity target) into contributions to economy-wide emission reductions. As a result, an assessment of NDCs for the resulting economy-wide emissions for those countries that do not provide an aggregate emission target is subject to interpretation.

Our assessment of the 2030 economy-wide reductions in GHG emissions for the ten ASEAN countries is provided in Table 2.1. The left-hand column lists our estimates of the *Baseline Scenario* emissions in 2030. The middle columns report 2030 emissions consistent with conditional and unconditional pledges. The right-hand columns report the 'emissions gap' for each country in 2030, measured as Baseline scenario emissions minus target emissions.

*The **Baseline Scenario** is a business-as-usual projection based on the current GDP and energy trajectory without enforcing the Paris Agreement pledges.*

Our analysis indicates that the ASEAN region has a sizeable emissions gap in meeting its Paris goals. In 2030, estimated ASEAN Baseline scenario emissions are 3,680 million tonnes of CO_2-equivalent ($MtCO_2e$) and the unconditional emissions target is 3,265 $MtCO_2e$. Consequently, the emissions gap is 415 $MtCO_2e$, which indicates that, in aggregate, the ASEAN region will have to reduce their emissions by 11% relative to the Baseline scenario. Under the conditional emissions target (2,781 $MtCO_2e$), the emissions gap is 899 $MtCO_2e$, which indicates a reduction of 24% relative to the Baseline scenario emissions. Country-specific projections are presented in Section 5 and additional details about country pledges are provided in Appendix A.

Figures 2.1 and 2.2 respectively illustrate individual countries' unconditional and conditional emissions gap in 2030. The two axes convey the magnitude of the gap in absolute terms and as a percent of the Baseline scenario emissions while bubble size is proportional to country Baseline emissions. Note that three ASEAN countries—Cambodia, Lao PDR, and Myanmar—define conditional targets only and therefore have no targeted reductions in Figure 2.1 while Malaysia has a small but positive unconditional reduction.

As shown in Figure 2.3, ASEAN emissions are expected to grow substantially with the current trajectory, and unconditional pledges represent a substantial decrease in the growth in emissions. As illustrated in Figure 2.4, emissions growth in the ASEAN region is expected to be driven by energy-related emissions.

Table 2.1. Modeling of NDC pledges and resulting emissions in 2030

Country	Baseline Emissions ($MtCO_2e$)	Modeled Target				Gap from Policy Scenario	
		Type	Reduction - Type	Relative to	Emissions ($MtCO_2e$)	Emissions ($MtCO_2e$)	%
Brunei Darussalam	13.9	UC†	45% - energy intensity of GDP	2005	10.3	4	26%
		C*	Same as UC	Same as UC	10.3	4	26%
Cambodia	15.3	UC	Baseline		15.3	--	--
		C	27% - emissions	Baseline in 2030	11.2	4	27%
Indonesia	1,450.3	UC	16% - emissions	Baseline in 2030	1,218.2	232	16%
		C	20% - emissions	Baseline in 2030	1,160.2	290	20%
Lao PDR	22.5	UC	Baseline		22.5	--	--
		C	10% - TPES	Baseline in 2030	21.4	1	5%
Malaysia	544.4	UC	35% - emission intensity of GDP	2005	539.8	5	1%
		C	45% - emission intensity of GDP	2005	456.8	88	16%
Myanmar	72.8	UC	Baseline		72.8	--	--
		C	20% fossil-based generation	Baseline in 2030	69.6	3	4%
Philippines	293.1	UC	Baseline		293.1	--	--
		C	70% - emissions	Baseline in 2030	87.9	205	70%
Singapore	51.4	UC	36% - emission intensity of GDP	2005	65.0	-14	-26%
		C	Same as UC	Same as UC	65.0	-14	-26%
Thailand	645.0	UC	20% - emissions	Baseline in 2030	516.0	129	20%
		C	25% - emissions	Baseline in 2030	483.7	161	25%
Vietnam	570.9	UC	8% - emissions	Baseline in 2030	525.3	46	8%
		C	25% - emissions	Baseline in 2030	428.2	143	25%
ASEAN	**3,679.6**	**UC**	**--**		**3,264.7**	**415**	**11%**
		C	**--**		**2,780.7**	**899**	**24%**

†Unconditional *Conditional

Note: Estimates exclude LULUCF-related emissions. Country emissions may not sum to the ASEAN totals due to rounding.

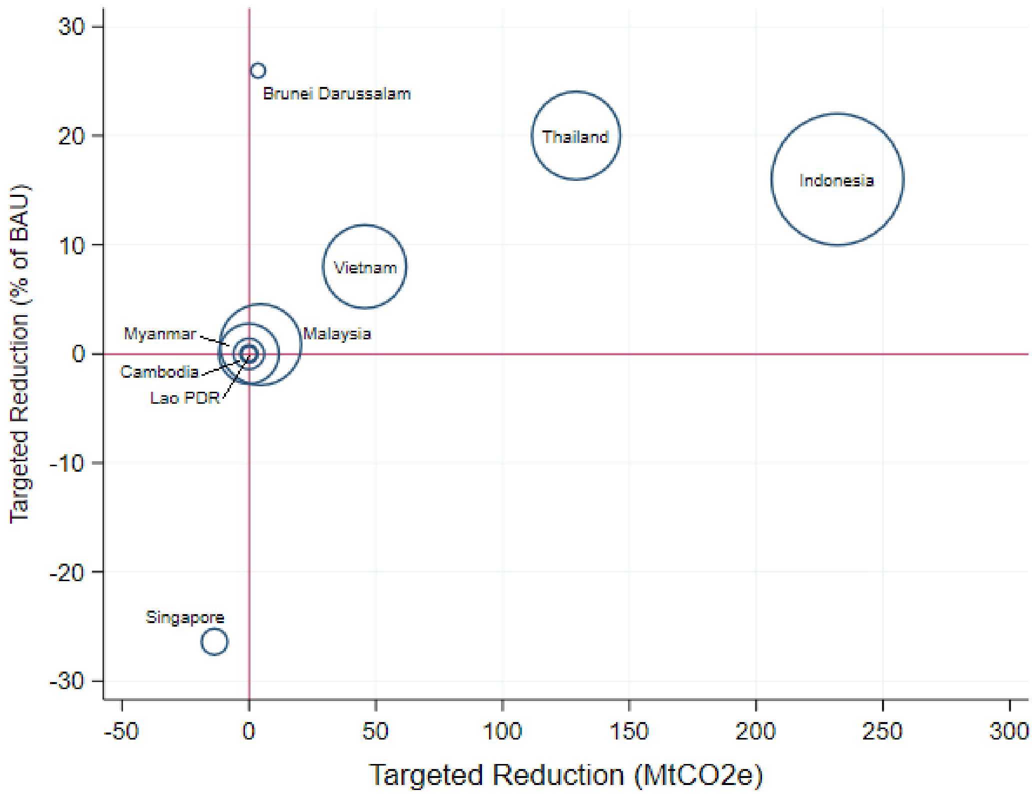

Figure 2.1. ASEAN countries' absolute (MtCO$_2$e) and relative (percent of Baseline) targeted emissions gap in 2030 under unconditional pledges. The bubble sizes are proportional to country Baseline emissions.

Figure 2.2. ASEAN countries' absolute (MtCO$_2$e) and relative (percent of Baseline) targeted emissions gap in 2030 under conditional pledges. The bubble sizes are proportional to country Baseline emissions.

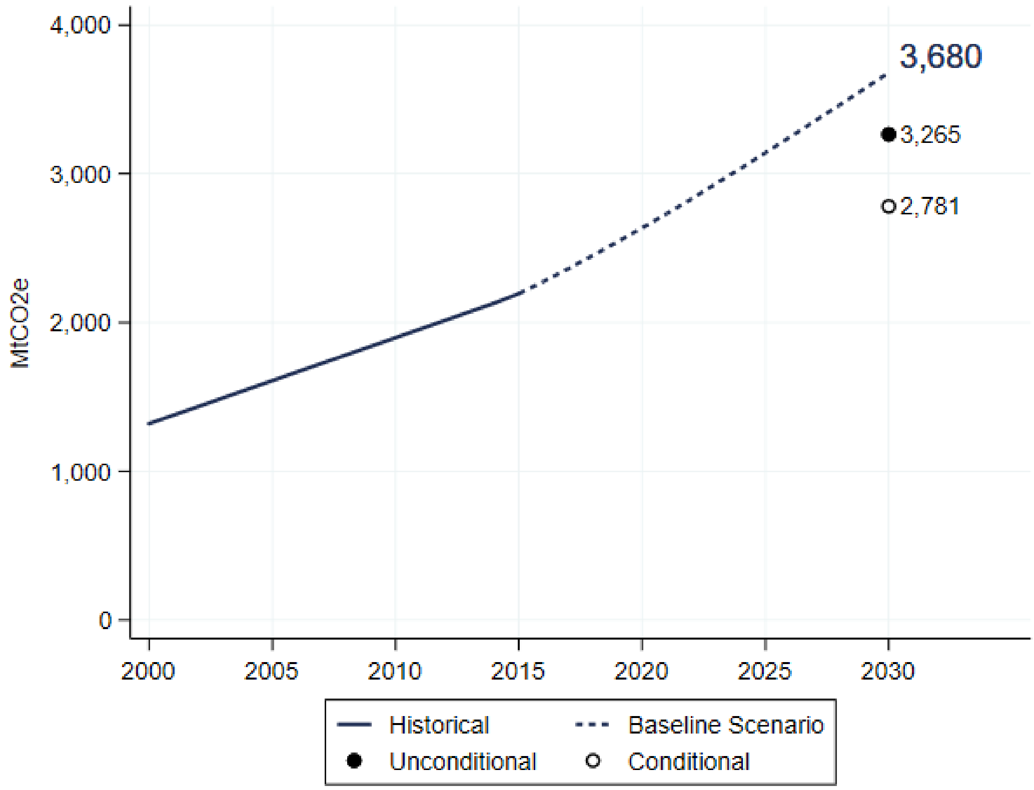

Figure 2.3. ASEAN's GHG emissions in 2000–2030 (excluding LULUCF) and the estimated unconditional emission reduction (full circle) and conditional emission reduction (empty circle).

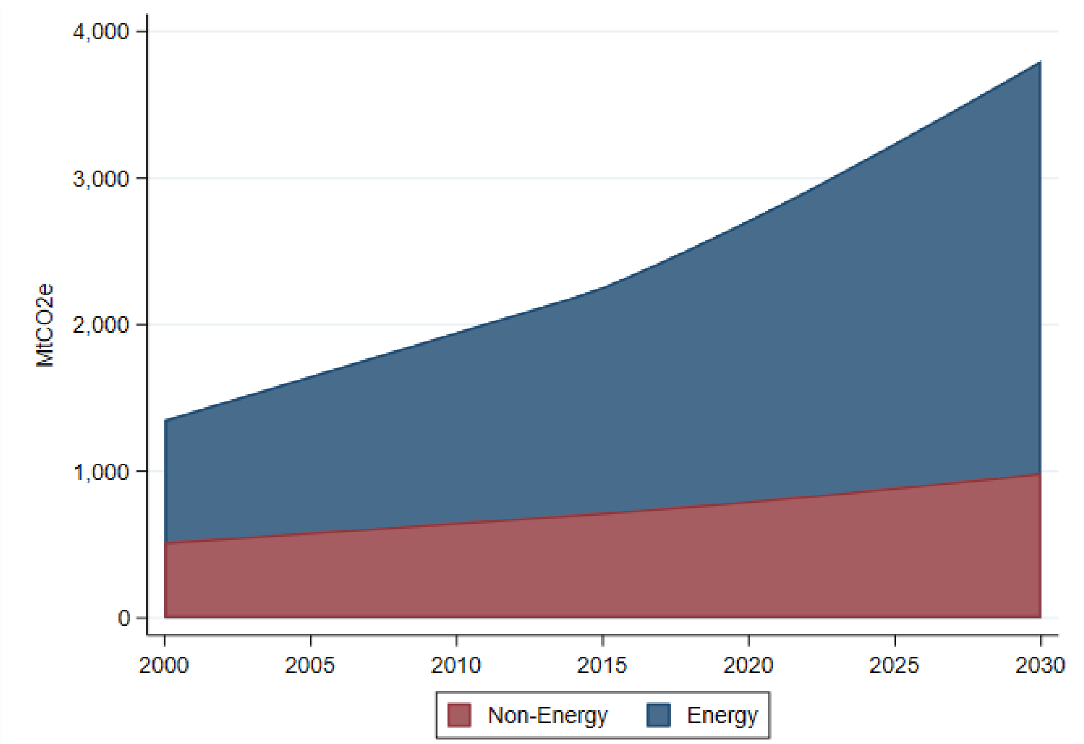

Figure 2.4. ASEAN's GHG emissions in 2000–2030 (excluding LULUCF) by energy and non-energy contributions.

3 Projected ASEAN Energy and Electricity Profiles to 2030

Main Takeaways

- The ASEAN region is rapidly growing in its energy and electricity consumption. From 2015 to 2030 energy consumption is projected to grow by about 80% while electricity use is projected to grow by about 115%.
- Solar and wind generation in the ASEAN is expected to grow five-fold between 2015 and 2030, but the ASEAN region continues to rely on fossil fuels for its energy needs. We project that the share of electricity generated from fossil fuels will change only slightly, from 82% in 2015 to 79% in 2030.
- We project that the main components of the ASEAN primary energy supply in 2030 will be oil (30% of total primary energy), natural gas (25%), and coal (23%). For electricity, the main sources of generation in 2030 are projected to be natural gas (39% of total generation); coal (38%), and hydro (12%).
- The three largest energy consumers in ASEAN—Indonesia, Thailand, and Vietnam—together account for 73% of both the regional primary energy and electricity generation in 2030. The five largest energy consumers in ASEAN—Indonesia, Thailand, Vietnam, Malaysia, and the Philippines—account for 93% of primary energy and electricity generation in 2030.
- The ASEAN countries show a wide range of electricity generation per capita, from 0.36 MWh per capita in Myanmar to 14.1 MWh per capita in Brunei Darussalam. Countries with low generation per capita may increase electricity production at a faster rate than countries with already high electricity generation per capita.

Our projection of ASEAN's primary energy supply in 2030: 30% oil, 25% natural gas, 23% coal, 18% biofuels/waste, 2% hydro, and 2% geothermal/solar/wind.

Energy use grows rapidly in the ASEAN region. Primary energy reflects an energy input to the energy system that has not been subject to energy conversion. It shows the amount of fossil fuels (coal, natural gas, oil) and renewable energy (hydro, biomass, wind, solar, and geothermal)[1] that is used in a country or a region. Total Primary Energy Supply (TPES) is the sum of production and imports subtracting exports and storage changes (IEA, 2017a). We project that the ASEAN TPES will grow by 82% from 620 million tonnes of oil equivalent (Mtoe) in 2015 (IEA, 2017a)[2] to 1,130 Mtoe in 2030. Expansion of TPES is driven by steady increases in oil, natural gas, and coal. While coal's share of total TPES increases from 19% in 2015 to 23% in 2030, the share of biofuels decreases from 20% in 2015 to 18% in 2030. Hydro and other renewables remain a small component of the aggregate TPES. We project that ASEAN TPES in 2030 will be 30% from oil; 25% from natural gas; 23% from coal; 18% from biofuels and waste; 2% from geothermal, solar, and wind; and 2% from hydro (Figure 3.1).[3]

We project electricity production[4] in the ASEAN region to grow by 114% from 915 terawatt hours (TWh) in 2015 (IEA, 2017a) to 1,955 TWh in 2030. The projected electricity growth is higher than the growth in TPES reflecting an increased electrification of energy use; however, both primary energy and electricity continue to rely mainly on fossil fuels. Additionally, while generation from both natural gas and coal drive overall generation growth, coal-fired generation is increasing in share of total generation from 35% in 2015 to 38% in 2030, while the share of natural gas falls from 42% in 2015 to 39% in 2030. Also notable, while an aggregate of geothermal, solar, and wind contributes only a small share of total generation, electricity

1 For primary energy accounting, we follow the physical energy content method adopted by the IEA. For a discussion of alternative methods, see Krey *et al.* (2014).

2 IEA (2017a) does not report TPES or electricity for Lao PDR, so the data for Lao PDR is sourced from ACE (2017).

3 In comparison, ACE (2017) projects 2030 TPES as 1,086 Mtoe with 35% oil, 21% gas, 35% coal, 4% hydro, 3% geothermal, 6% other renewables, and 8% traditional biomass.

4 We use the terms "electricity production" and "electricity generation" interchangeably.

production from these technologies increases almost five-fold from 2015 to 2030. Altogether, electricity generation mix in 2030 is projected to be of 39% natural gas; 38% coal; 12% hydro; 2% oil; 8% of an aggregate of geothermal, solar, and wind; and 1% of an aggregate of biofuels and waste (Figure 3.2).[5]

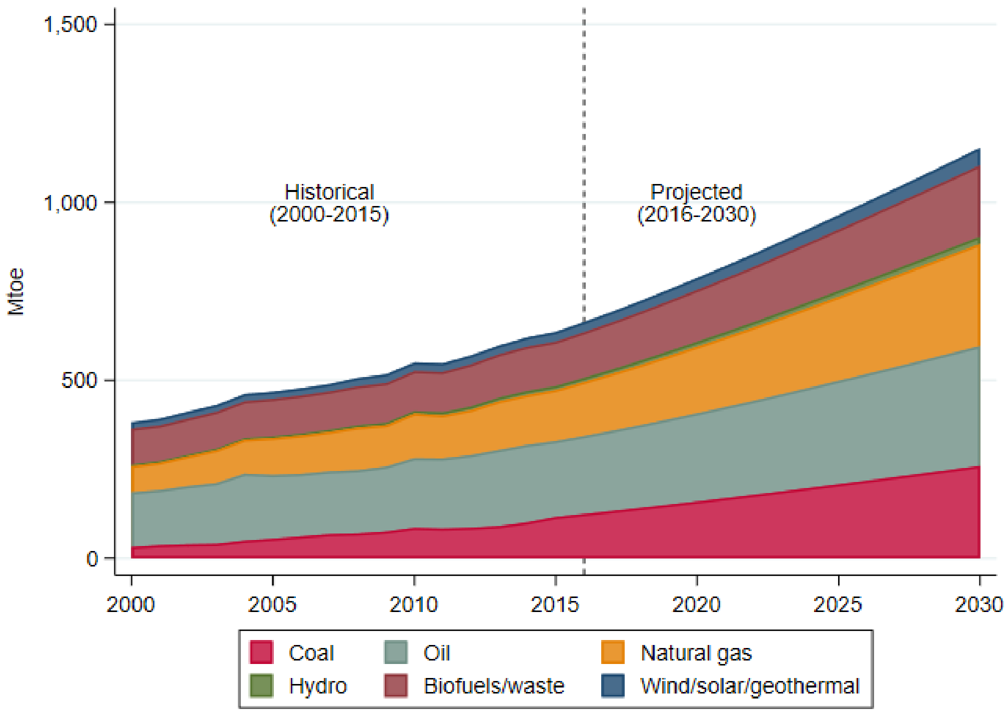

Figure 3.1. ASEAN Total Primary Energy Supply by Fuel Type.

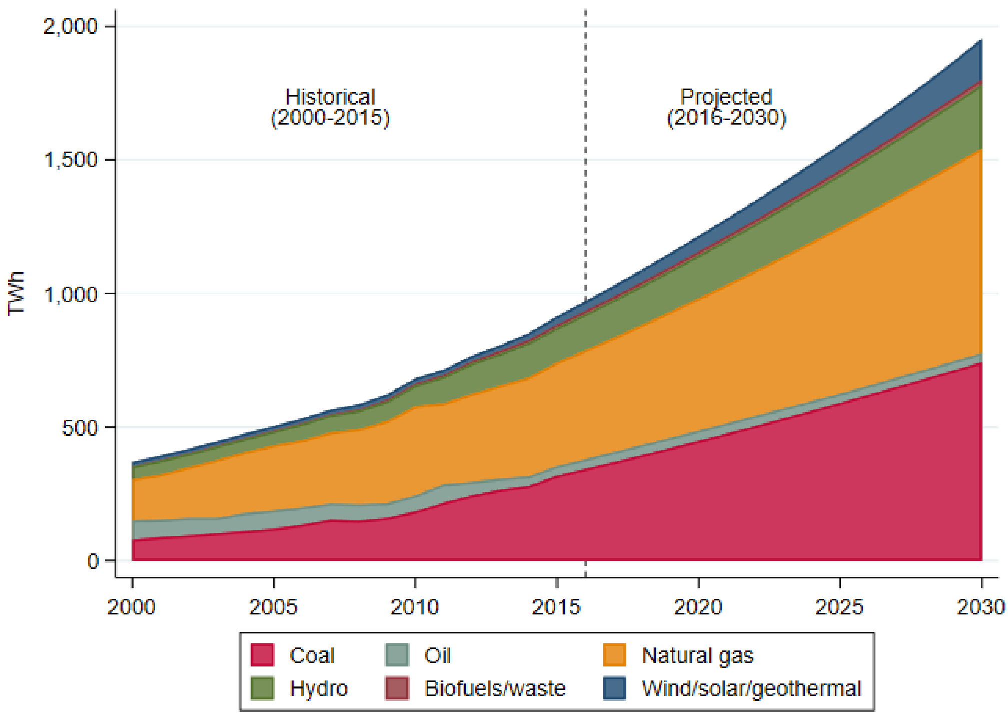

Figure 3.2. ASEAN Power Generation by Fuel Type.

5 ACE (2017) projects 2030 electricity generation as 1,864 TWh with 31% natural gas, 38% coal, 21% hydro, 4% oil, 2% geothermal, and 4% of other renewables.

Of the ten ASEAN member states, Indonesia is the largest energy consumer accounting for 38% of the regional TPES in 2030 (Figure 3.3) and 37% of ASEAN electricity generation in 2030 (Figure 3.4). Three largest energy consumers, Indonesia (427 Mtoe and 728 TWh in 2030), Thailand (224 Mtoe and 318 TWh in 2030), and Vietnam (178 Mtoe and 376 TWh in 2030), together account for 73% of both the regional TPES and electricity generation in 2030. Adding Malaysia (145 Mtoe and 271 TWh in 2030) and the Philippines (78 Mtoe and 130 TWh) results in the top five countries of the ASEAN accounting for 93% of TPES and 93% of electricity generation.

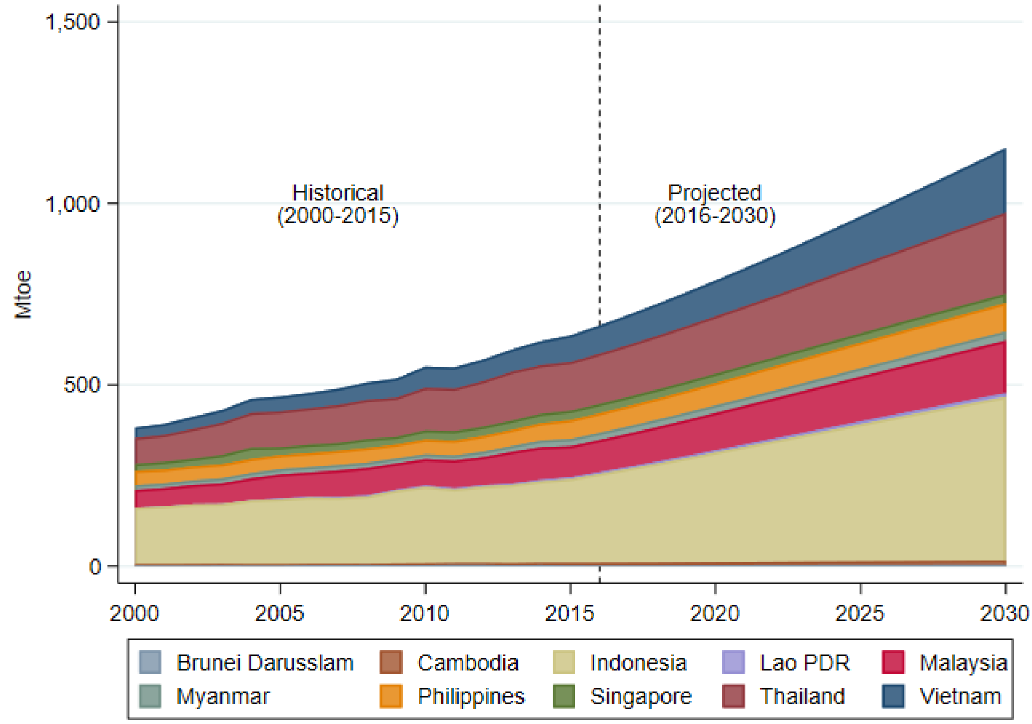

Figure 3.3. ASEAN Total Primary Energy Supply by Country.

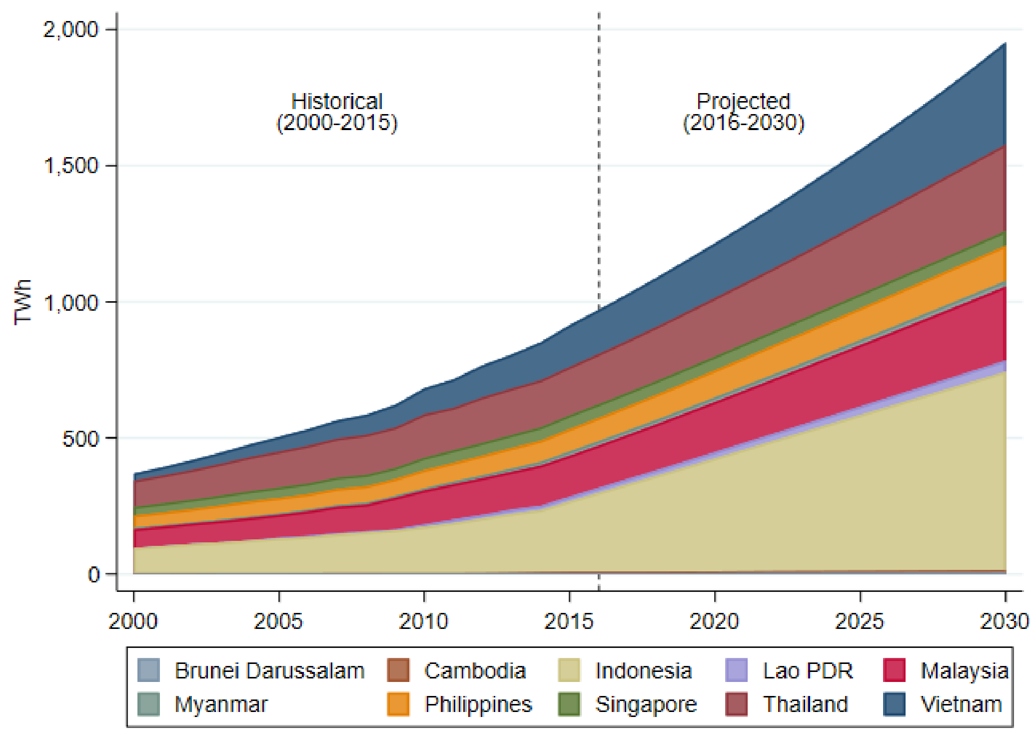

Figure 3.4. ASEAN Power Generation by Country.

A useful metric to gauge potential expansion in the power generation sector is generation per capita. Countries with a low generation per capita might increase electricity production at a faster rate than countries that already have high electricity generation per capita. To calculate this metric, we relate electricity use to the historical and projected population in each country for the years 2000 to 2030 estimated by the UN (UN, 2017). Population is expected to grow steadily in all ten ASEAN countries, with the average annual growth rate in 2016–2030 ranging from 0.1% in Thailand to 1.4% in The Philippines (Figures 3.5–3.6).

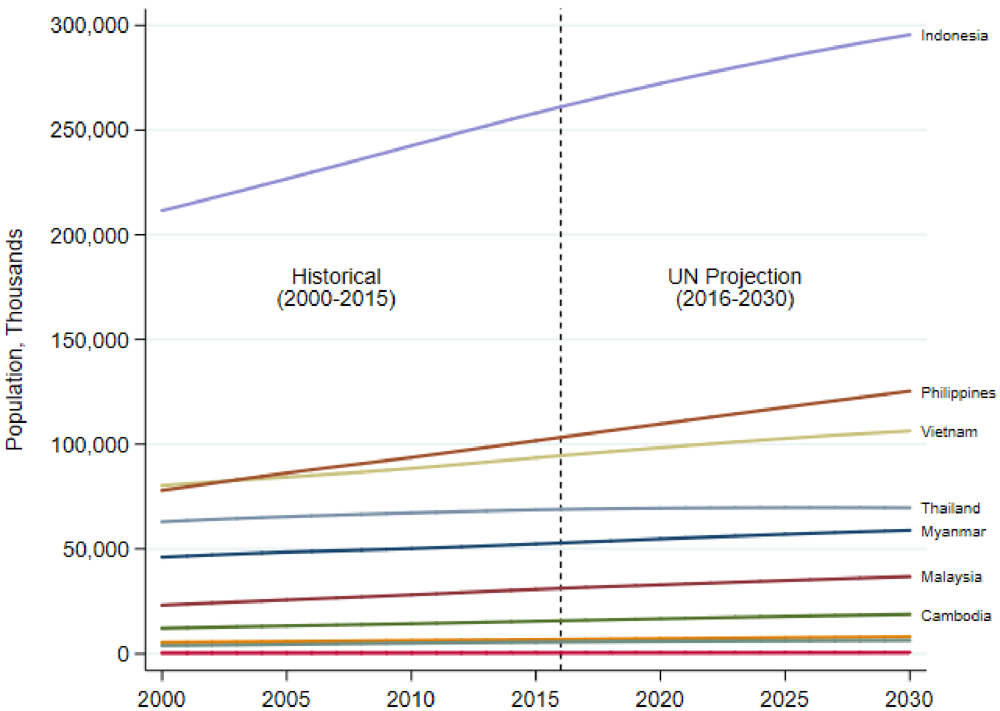

Figure 3.5. ASEAN countries population (all countries).

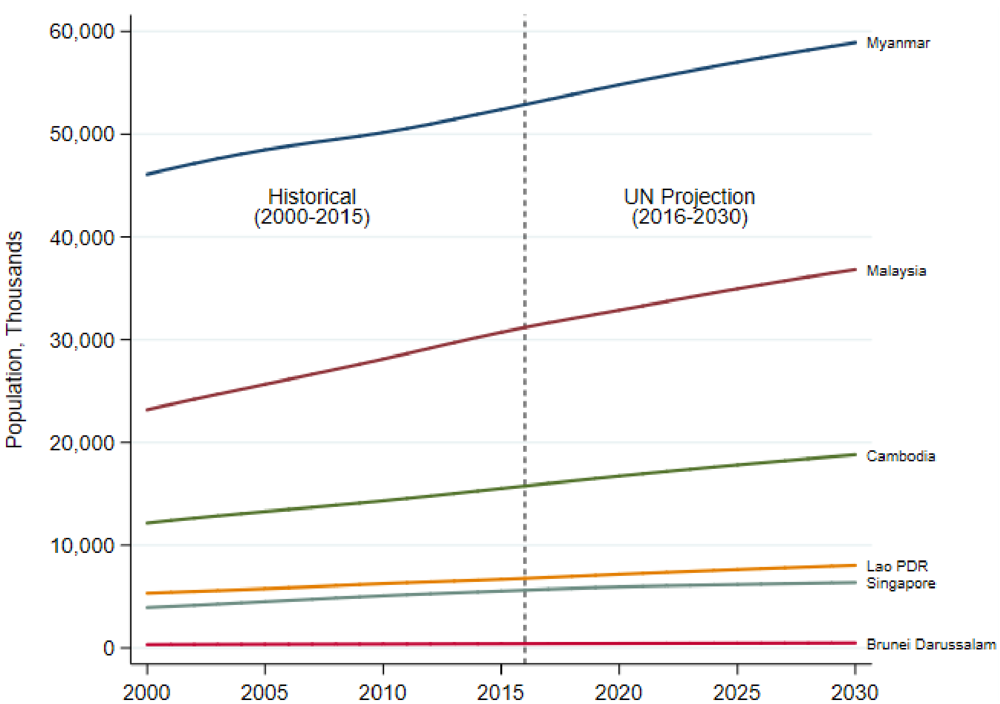

Figure 3.6. ASEAN countries population (smaller countries).

Figures 3.7–3.8 show the wide range of electricity generation per capita in the ASEAN countries. In our Baseline projections, in 2030 it ranges from 0.36 MWh per capita in Myanmar to 14.1 MWh per capita in Brunei Darussalam[6]. Achieving NDC goals will be affected by the type of the power generation added in each country. For example, investments in coal power plants (without carbon capture and storage, or CCS) would lock-in substantial carbon emissions

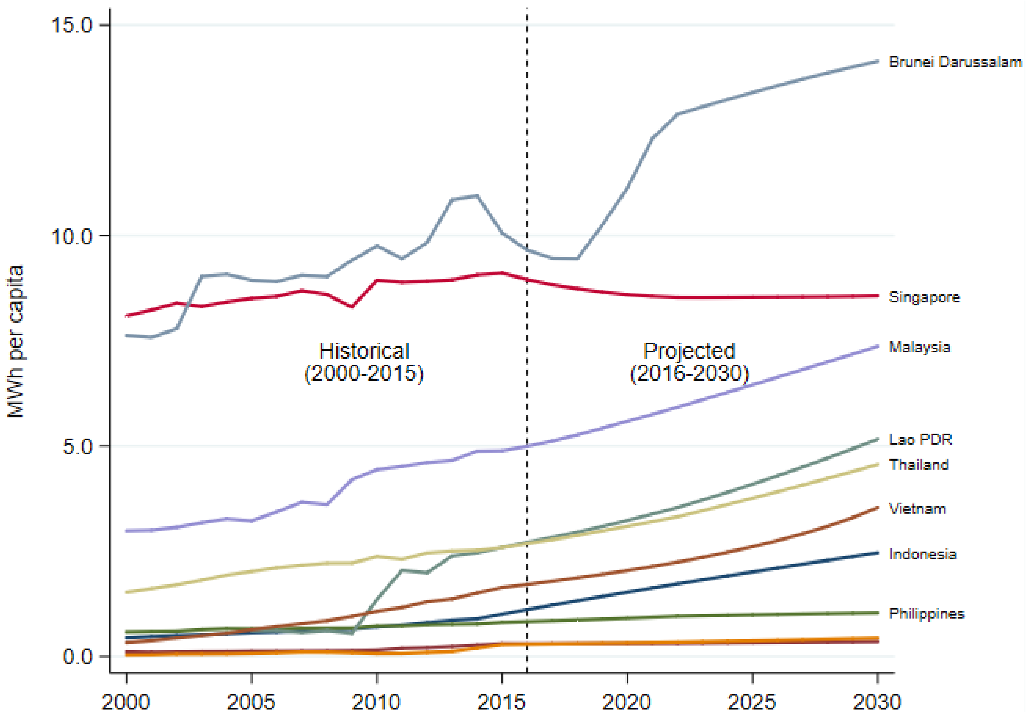

Figure 3.7. ASEAN power generation per capita (all countries).

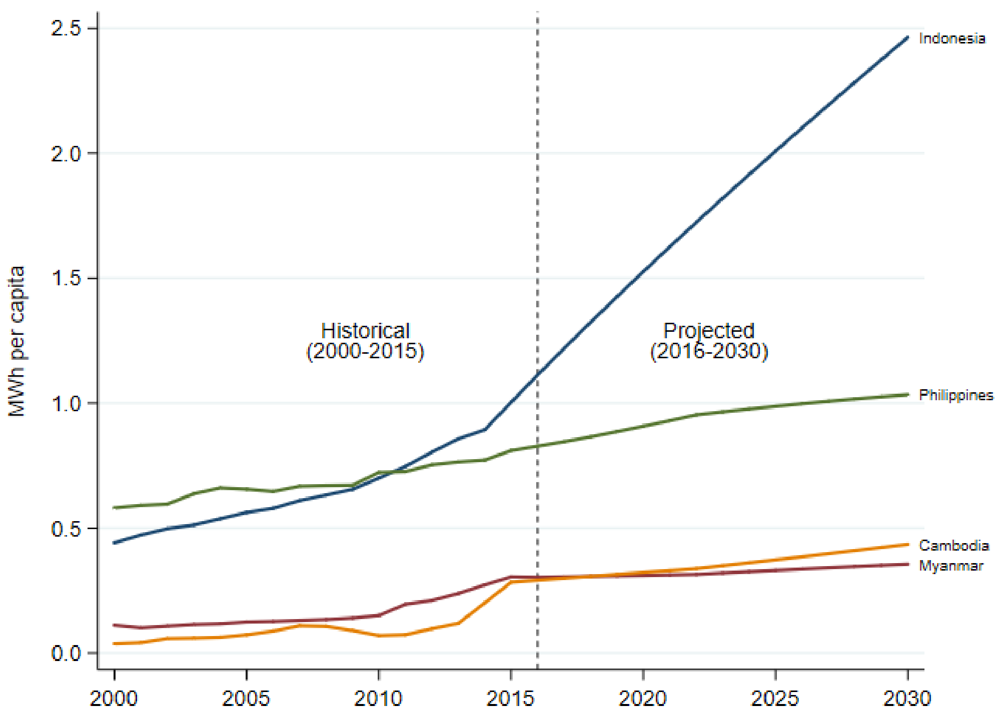

Figure 3.8. ASEAN power generation per capita (low generation per capita countries).

6 We project that per capita electricity in Brunei Darussalam recover from a downturn driven by low natural gas and oil prices that affected demand. Singapore is projected to continue its increase in energy efficiency while increasing population growth resulting in a slight decrease in electricity per capita by 2022 and flattening afterwards.

associated with coal use, while investments in natural gas-based generation, which has lower carbon intensity than coal, or investments in wind and solar that have zero carbon emissions associated with power generation, would pave the road for more aggressive emission reductions. At the same time, coal power in many countries is the cheapest and most reliable energy option. The ASEAN region is unique in terms of the medium-term prospects for its coal generation. According to IEA (2017b), it is the only region of the world where the share of electricity generation from coal is projected to substantially increase.

The high efficiency low emission (HELE) coal plants (IEA CCC, 2016) provide an option for lower carbon emissions and significantly reduced (to the level of natural gas plants) emissions of sulphur dioxide (SO_2), nitrogen oxides (NOx) and particular matter (PM). However, if carbon emission reduction goals after 2030 would be substantially increased in the ASEAN countries, then additional reduction of carbon emissions would require CCS. The current progress on CCS development is rather slow (with only a few power plants at a commercial scale) and the ultimate fate of coal would depend on the cost of investing in CCS versus abandoning or converting the generating assets.

4 Policy and Technology Options for ASEAN to Reduce Emissions

The ASEAN countries in their NDCs list numerous plans, policies, and strategies as the means of implementation of their emission reduction goals.[1] The current country-specific policy instruments are described in the individual countries sub-sections of Section 5. In this section, we provide a discussion of options for emission mitigation technologies and policy instruments ASEAN countries can consider. Then, Section 7 offers a short overview of the experiences with these and other emission reduction policies in different parts of the world, where some countries have had a remarkable success in using policy tools to advance decarbonization. Policy frameworks are the keys to determine the ability of a nation to incentivize a deployment of new technologies, attract private capital, internalize externalities (such as health effects of air pollution), modernize transmission and distribution and expand access to energy. These policies range from broader policies like energy price reforms and reducing energy subsidies to technology-specific policies like renewable portfolio standards, feed-in tariffs and renewable energy auctions. Below we offer a discussion of the main characteristics of emission reduction policy options. At the end of this section we offer our recommendations for the ASEAN countries regarding the use of specific instruments.

4.1 Policy Measures

Main Takeaways

- An increase in GHG emissions and the resulting climate change is caused by various market failures, and different policy instruments are available to correct these. Some policy instruments are more cost-effective than others in achieving mitigation targets, with economic instruments typically offering the most favorable ratio of benefits to cost.
- Carbon pricing through taxes or cap-and-trade systems tends to be the most cost-effective choice for climate change mitigation, but can be politically challenging to implement and does not address all market failures equally well.
- Other policy instruments are therefore needed, for instance to promote clean technology innovation, provide necessary infrastructure, and ensure an enabling investment context. Countries therefore tend to implement portfolios of instruments.
- To avoid adverse interactions between policy instruments in such a portfolio, each instrument should ideally pursue one clearly defined goal. That said, successful implementation of policy instruments often depends on other conditions to be met, calling for a package of mutually supportive and consistent measures.
- Such conditions include institutional, regulatory, and planning frameworks. An example is the regulatory design of electricity markets, where multiple factors have to be properly aligned to allow policy instruments for renewable energy promotion to achieve their full potential.

4.1.1 Conceptual Framework and Typology

Policies to support low-carbon technologies are commonly justified with the need to address the environmental impacts of conventional technologies. One policy approach is to address the negative externalities (or unaccounted-for social costs) of fossil fuel combustion, such as the environmental and health impacts of pollution. Without corrective policies, rational individuals fail to act in the common interest (Hardin, 1968; Olson, 1968; Ostrom, 1990), and as

1 Many of these documents are not easily accessible, while the available documents vary substantially in their specificity about the policy instruments and their implementation. In many cases, documents provide rather general statements about the desired goals without providing substantial details about the ways to implement the intended actions.

a result, society (rather than the polluters) bears the cost of the externalities, causing market distortions and an inefficient allocation of resources (Bator, 1958; Buchanan *et al.*, 1962).

Corrective policies can take the form of a price on polluting behavior (Pigou, 1920; Baumol, 1972), quantity controls with markets for tradable pollution permits (Dales, 1968, based on Coase, 1960), other types of quantity controls (such as performance standards), or technology mandates. Such policies benefit low-carbon technology by requiring their use, as in the case of renewable energy mandates, or by increasing the cost (or even forbidding the use) of conventional technologies to make them relatively less competitive, as in the case of carbon taxes and coal phase-out mandates. Section 7 provides case studies of the implementation of different policy approaches in practice, focusing on the particular lessons learned in each policy context. Case studies include carbon taxation (Section 7.3.4), markets for tradeable permits (Sections 7.2.2, 7.3.1–7.3.3), and performance standards (Section 7.2.1).

But climate policies can also target other market failures beyond negative externalities, such as the inability of economic actors to capture positive externalities, or unaccounted-for social benefits. Such positive externalities can include innovation effects, improved energy security, or structural transformation towards greater competitiveness and employment (IRENA, 2016). If these positive externalities are not internalized, then the full social benefit of researching, developing and deploying renewable energy technology is not received. Subsidies, price supports, and protection of intellectual property rights are examples of policies to internalize positive externalities, either by compensating economic actors whose behavior results in spillover benefits, or by avoiding the spillover in the first place (see case studies in Sections 7.1.1–7.1.2). Finally, policy interventions can also be justified by the need to address behavioral and institutional barriers impeding investment in low-carbon technology, such as the bounded rationality of economic actors, information asymmetries, split incentives, or restricted access to capital (Labandeira *et al.*, 2011).

These distinctions matter because each rationale favors different policies, with reasoned disagreement on the 'first best' solution. Policies directing technological change, such as subsidies or technology mandates, risk allocating resources to unnecessarily costly or dead-end technologies because of the imperfect information available to policy makers (Anadon *et al.*, 2016). Carbon pricing (through taxes, see case study of British Columbia in Section 7.3.4) or quantity controls with tradeable units (e.g., cap-and-trade, see case studies of Europe and North America in Sections 7.3.1–7.3.3) both let the market determine the allocation of resources and can thereby spread carbon abatement costs across all parties while still being cost-effective and avoiding technology-picking (Fischer *et al.*, 2008). However, these policy instruments may not promote early-stage innovation or address behavioral and institutional barriers (Acemoglu *et al.*, 2012; Bertram *et al.*, 2015). Additionally, carbon pricing policies may be more susceptible to political change and stakeholder pressure than some policy alternatives (Meckling *et al.*, 2015; Jenkins *et al.*, 2016; see also European case study in Section 7.3.1). What is more, if insufficiently robust, carbon pricing (as well as other climate policies) can allow continued investment in long-lived carbon-emitting technologies, risking carbon lock-in and technological path dependencies (Bertram *et al.*, 2015; Seto *et al.*, 2016; Unruh, 2000). Table 4.1 provides a summary of the different policy instruments based on intensive literature reviews. Considerations for instrument choice, instrument portfolios, and the role of energy markets are discussed in the following subsections.

Table 4.1. Typology of Policy Instruments

Policy Category		Policy Instrument	Characteristics and Assessment
Price Controls		Carbon tax (Pigovian tax)	Generally considered the most cost-effective and least distorting policy option. Political constraints tend to force tax rates lower than the social cost of carbon (Jenkins *et al.*, 2016); carbon taxes target the negative externality of carbon emissions, not other market failures; hence may not be sufficient to overcome behavioral barriers to low-carbon technology investment and early stage R&D
Price Controls		Feed-in tariffs, feed-in premiums, generation-based direct payments, and other (non-fiscal) price support measures	Can be very effective incentive for low-carbon technology investment due to long-term predictability of ROI, reducing capital costs; but risks promoting dead-end technologies due to imperfect information available to policy makers; needs frequent adjustments because of uncertainty in the deployment levels of low-carbon technology
Quantity controls[1]	**WITH** trading	Emissions trading (cap-and-trade, baseline-and-credit schemes)	Theoretically as cost-effective as a Pigouvian carbon tax under conditions of certainty (Weitzman, 1974). More favorable political economy due to flexibility when allocating allowances and thus distribution of compliance burden; cap/baseline rarely stringent enough to yield prices equal to the social cost of carbon; low prices and price volatility can deter low-carbon technology investment; may not be sufficient incentive for early stage R&D in low-carbon technology
Quantity controls[1]	**WITH** trading	Green/white certificate schemes (e.g. renewable portfolio standards with trading)	Effectively incentivizes low-carbon technology investment; price volatility can be a deterrent to RE and energy efficiency investment, and increase capital cost; may not be sufficient incentive for early stage RD&D
Quantity controls[1]	**WITHOUT** trading	Auctions	Effectively incentivizes RE investment deployment at very low cost; quantity certainty offers predictability of RE deployment; may not be sufficient incentive for early stage RD&D
Quantity controls[1]	**WITHOUT** trading	Performance standards	Can be set to effectively require low-carbon technology and infrastructure investment, but at high compliance cost; risks promoting dead-end technologies due to imperfect information
Technology Controls		Technology standards	Can be set to effectively require low-carbon technology investment, but at high compliance cost; risks promoting dead-end technologies due to imperfect information
Technology Controls		Permitting and licensing requirements	Specify permitted activities and related obligations, and afford high degree of regulatory certainty, at the expense of flexibility and cost effectiveness; should be limited to activities where certainty of outcome is critical
(Fiscal) Subsidies		Grants	Effectively incentivize low-carbon technology investment deployment, but at a corresponding fiscal cost; risk promoting dead-end technologies due to imperfect information available to policy makers
(Fiscal) Subsidies		Credits and rebates (production & investment tax credits, reduction in energy and other taxes)	
(Fiscal) Subsidies		Depreciation rules	
(Fiscal) Subsidies		Loan guarantees	
Suasive Instruments		Labeling and information	Can help overcome information asymmetries and influence consumer choices; causal effect difficult to measure
Suasive Instruments		Mandatory audits	Formalized review and evaluation, often involving accredited third-party auditors or verifiers, can improve data availability and quality, compliance rates, and enforcement, but incur a financial burden
Suasive Instruments		Energy management/Corporate Social Responsibility (CSR) systems	Voluntary private sector initiatives; uptake dependent on individual cost/benefit assessment; can include renewable energy deployment; but reduced accountability due to voluntary nature
Planning Instruments		National action plans, programs and strategies	Broad, overarching process to inform decision making, identify cost/benefit of alternative options, and balance competing objectives; important to chart long-term policy roadmaps and avoid adverse interactions between individual instruments
Planning Instruments		Resource & infrastructure planning (e.g. resource mapping, siting and zoning, and grid integration plan)	

1 Emissions targets, energy efficiency improvement targets, renewable energy quota, etc.), achievable *inter alia* through controls with or without trading.

4.1.2 Instrument Choice

4.1.2.1 Criteria of Instrument Choice

As outlined in the preceding subsection, decision makers can look to a diverse portfolio of policy instruments for climate change mitigation. In practice, these instruments are applied alone or in varying combinations to different sectors, such as electricity generation, transport, buildings, and industry (Krupnick *et al.* 2010). In choosing the most suitable policy instruments, decision-makers consider a variety of criteria. Economic theory and other academic disciplines can inform the selection of individual instruments and their arrangement in an optimal policy mix. While no single set of criteria is universally sufficient (Goulder *et al.*, 2008), a number of recommended criteria have gradually evolved to evaluate individual instruments and justify their selection. The following criteria are often proposed (Baumol and Oates, 1988; Goulder *et al.*, 2008; Harrington *et al.*, 2004; Keohane *et al.*, 1998; OTA, 1995; Sterner, 2003): environmental effectiveness, cost effectiveness, distributional considerations, and institutional feasibility (see Table 4.2).

Instrument selection is often complicated by conflicting criteria, meaning tradeoffs are inevitable, and policy selection is largely dependent on specific circumstances (Goulder *et al.*, 2008). Additionally, as mentioned in the preceding subsection, climate policies tend to address several market failures and pursue more than one objective (Knudson, 2009: 308), and the extreme uncertainties surrounding the causes, impacts, and policies of climate change further complicate instrument evaluation (Weitzman, 2009).

Finally, and perhaps most importantly, experience has shown that policies are influenced by many other motivating factors, suggesting that both practical, in-field experience and analytical, literature-based knowledge should be used to assess existing instrument portfolios. In particular, political, regulatory and institutional parameters—which are specific to a given geographic and socioeconomic context—can be difficult to capture when evaluating policies. The role of these parameters is briefly described in the following subsection.

Table 4.2. Criteria of Instrument Choice

Environmental effectiveness	Cost effectiveness
How well does a policy instrument meet its intended environmental objective? How certain is its level of environmental impact?	Can the policy achieve its objectives at a lower cost than other policies? Does it create revenue streams that can be reinvested?
Distributional considerations	**Institutional feasibility**
How does the policy impact consumers and producers? Can it be considered fair and equitable?	Is the policy instrument likely to be viewed as legitimate, gain political acceptance, be adopted and ultimately implemented?

4.1.2.1 Political, Regulatory and Institutional Parameters

Political preferences at any given point in time are difficult to capture and describe, let alone in terms that are transferable to different historical and geographic contexts. Various academic disciplines and methodological approaches, ranging from political science to the behavioral sciences and game theory, have sought to study and understand political processes, including how policies are selected and implemented. In economics, a growing body of climate policy literature has significantly contributed to the understanding of the different people, groups, and interests involved in selecting and applying policy instruments.

For instance, research has highlighted the political challenges of carbon pricing, which exposes private costs and disproportionately burdens a limited group of politically influential emitters while spreading the benefits of climate change mitigation among many poorly organized constituents (e.g. Jenkins *et al.*, 2016). As such, a price on carbon suffers from the same susceptibility to regulatory capture—that is, lobbying and rent-seeking by affected interests, resulting in less efficient policy designs and distributional outcomes—that already afflicts many policies adopted for the collective interest (Olson, 1968; Stigler, 1971). Research has therefore suggested that other types of instruments—such as price support measures and fiscal subsidies—can be more successful in building coalitions of support (Meckling *et al.* 2015), and have also been shown to be more popular with the public in opinion surveys (Krosnick and MacInnis 2013). Due to this greater level of support, such policies can be sustained and grow even more ambitious over time (Wagner *et al.*, 2015), suggesting that a phasing-in of carbon pricing after establishing these other policies may be a more effective approach (Pahle *et al.* 2017).

Regulatory and institutional parameters are more straightforward to study, using methods and frameworks from political science, government and public administration studies, institutional economics, and law. These disciplines affirm that rules and institutions set out the behavioral parameters—meaning the rights and duties—of public and private actors as well as the objectives of public policy, and create the regulatory environment in which policy instruments operate (see e.g. on the role of electricity market regulation Section 4.1.4). Failure to ensure the compatibility of policy instruments and their regulatory context will not only compromise their ability to function, but may also threaten their legality. Formal institutions, such as government agencies or intergovernmental bodies, strictly embody these parameters through internal mandates, procedures and dynamics. More informal institutions surrounding culture, habits, and customs also play an important, yet subtle, role. While these institutions have a less obvious influence on policy than the binary permissibility (or lack thereof) of traditional rulemaking, they still have a profound impact on the feasibility and implementation of different policy options.

Overall, these considerations play an important role in the selection of instruments for climate policy. An area's specific legal and institutional context affects not only how policies operate—determining their viability and relative appeal—but also how policies are developed. A policy instrument pursued without adequate consideration of these parameters is less likely to be adopted and, if adopted, less likely to be durable and effective—both in terms of mitigation and cost—than instruments that are more consistent with their political, regulatory, and institutional context. Weak administrative capacities, legal challenges, and unclear mandates can in theory undermine the implementation of even the most effective and efficient instrument, as seen in the operation of complex policy instruments such as emissions trading systems. Likewise, the success of renewable energy or energy efficiency support measures can depend more on the legal frameworks protecting investments in low-carbon technology rather than the design and implementation of the measures themselves.

When determining the type and form of climate policy instruments, decision makers will typically have to balance a number of priorities and trade-offs. A legal mandate for climate policy measures and pre-existing rules and doctrines (including judicial precedent) will help determine the permissibility and scope of climate action.[2] Different options require different procedures, impacting the timeline and degree of stakeholder participation; this in turn can affect the policy option's acceptance, perceived legitimacy, and ultimately its durability, which is particularly important to provide a stable investment context for investors in long-lived, capi-

2 In most jurisdictions, the executive branch of government will require a legal basis for action, including the implementation and enforcement of policies as well as the elaboration of more detailed technical rules and guidelines; this tenet—sometimes referred to as the doctrine of statutory reservation—is a fundamental requirement of the rule of law.

tal-intensive clean technologies and infrastructure. Finally, different types of legal instruments will also be more or less resilient to judicial review and political changes. Table 4.3 summarizes these legal and institutional parameters.

As already mentioned, however, assessing the political, regulatory, and institutional parameters of climate policy making cannot occur at an abstract level; instead, inquiry into a specific jurisdiction's legal and institutional structures is needed. This need for a survey of existing regulatory and institutional arrangements may also explain why these criteria are rarely applied in mainstream literature on instrument choice, especially at any level of detail. The role of political, regulatory and institutional considerations in policy choice can only be assessed within a specific legal and institutional context, and therefore requires an in-depth analysis of a country's particular circumstances.

Table 4.3. Legal and Institutional Criteria of Instrument Selection

Legality		Process		Flexibility		Durability	
Legal Precedent	Extant Law	Duration	Participation	Certainty	Adjustability	Judicial Review	Political Change

4.1.3 Instrument Portfolios and Policy Interaction

Since different policy objectives generally require their own policy instrument (Tinbergen, 1952; Johansen, 1965), governments will usually introduce a portfolio of instruments. This allows combining instruments to harness their respective strengths, but can come at the risk of interactions and reduced overall efficiency (Böhringer *et al.*, 2008; Fankhauser *et al.*, 2010; Fischer *et al.*, 2010; OECD, 2007; Rausch and Karplus, 2014; Paltsev *et al.*, 2015). Instrument interactions are particularly likely where policies pursue more than one objective or undermine other policy objectives and therefore necessitate tradeoffs (Knudson, 2009). Depending on the instrument type, objectives, and context, such interactions can be positive or negative. They are more likely to be beneficial when each of the affected instruments addresses a different market failure with sufficient specificity, whereas adverse interactions are more likely when multiple policies seek to correct the same market failure (IPCC, 2014).

While intended to promote mitigation at least cost, carbon pricing is also vulnerable to adverse interactions when implemented alongside other policy instruments targeting carbon emissions. Performance standards set for particular technologies will interfere with the ability of carbon pricing to equalize abatement cost across the economy and identify the most cost-effective abatement options. If the carbon price is higher than the marginal abatement cost under such complementary policies, it becomes redundant (IPCC, 2014); if the carbon price is lower, by contrast, the simultaneous application of directed technology mandates will curtail the compliance flexibility of emitters and increase the cost of achieving the same environmental outcome.

With a quantity rationing approach that involves tradeable units, such as an emissions trading system, the introduction of complementary policies can be particularly counterproductive. Because the overall emissions level is determined by the supply of units, emissions reductions achieved under the complementary policy will displace units that can be used to offset emissions elsewhere under the ETS, effectively only shifting the location and timing of emissions under the determined limit (Burtraw *et al.*, 2009; Goulder and Stavins, 2011; Goulder, 2013). Additionally, the increase in unit supply will, *ceteris paribus*, exert downward pressure on unit prices, subsequently increasing unit demand (Goulder *et al.*, 2013) and weakening the price signal in the market. A striking example of this dynamic playing out in practice has been the experience under the European Union emissions trading system (EU ETS), where simultaneous operation of the trading system alongside targeted instruments to promote energy efficiency improvements and renewable energy deployment contributed to a severe imbalance of supply and demand in the carbon market, resulting in a prolonged collapse of allowance prices and a carbon price signal that has been too weak to promote fuel switching in the power sector, as intended (see below, Section 7.3.1).

For climate policy makers exploring the adoption of multiple climate policy instruments as part of an instrument portfolio, the foregoing observations translate into a number of recommendations. A starting point can be derived from the Tinbergen Rule mentioned earlier: just as each target requires its own policy, each policy should seek to address a different market failure, and do so with the greatest level of specificity possible. Policies adopted to promote climate mitigation should thus avoid the simultaneous pursuit of other policy objectives, such as labor or industrial policy goals (Görlach, 2014).

In practice, of course, concurrent policy objectives and instruments are not always clearly defined or easily distinguishable (Tinbergen, 1952). Political and institutional dynamics tend to result in policy accretion (Helm, 2005), where some policy instruments are introduced for purely symbolic reasons or concealed motivations. Also, negative policy impacts, for instance on low-income households or vulnerable industries, may require additional policy interventions, further increasing the number of instruments in the mix. Given these political economy considerations and the pressure for policies to pursue multiple policy priorities, limiting the overall number of instruments should be another guiding principle (Knudsen, 2009).

The previous paragraphs summarize the economic theory on use of multiple policy instruments to address specific market failures. It is important, however, to note that several different market failures contribute to climate change (see Section 4.1), justifying separate sets of instruments. In a real-world context, moreover, policy instruments often depend on additional flanking measures to create an enabling context and secure effective implementation. While it remains important, thus, to avoid policy portfolios with multiple priorities and objectives, once a core policy instrument has been selected for each market failure, this instrument may need to be fortified with complementing measures that further support achieving the instrument's objectives. Without an internally consistent and mutually supporting policy framework, advancing complex projects and securing investment decisions can become significantly more challenging.

This is particularly relevant for climate policies whose successful operation depends on multiple other conditions being met. For example, feed-in-tariffs alone cannot increase renewable penetration without streamlined rules on environmental and land use planning, as well as supportive permitting and grid access policies and procedures. In many countries, renewable energy deployment and diffusion have been hindered or slowed down by insufficient provision for renewable energy integration, such as grid access, grid interconnection, and enabling grid operation practices (see, e.g., the case study of Brazil in Section 7.1.2). Likewise, policies and market design parameters that can advance supply- and demand-side flexibility, and policies to promote increased storage capacities in the grid, can greatly help accelerate renewable energy deployment (see below, Section 4.1.4). Thus, in a practical business environment, focusing on only one core policy instrument without ensuring an adequate, enabling framework of complementary planning, regulatory, market design and other related

Focusing on only one core policy instrument without ensuring an adequate, enabling framework of complementary planning, regulatory, market design and other related measures may limit the effectiveness of that policy.

measures may limit the effectiveness of that policy and fail to create the required certainty for investment, in particular for the introduction of new and clean energy technologies.

Thus, while the theoretical literature cautions against mixing core policy instruments with multiple objectives, it is advisable to embed each policy instrument in a package of policies and measures that complement each other to support a common objective, increasing the overall effectiveness of each instrument.

4.1.4 The Role of Electricity Market Design

Although not a policy instrument in itself, electricity market design plays an important role in meeting climate policy objectives. Historically, the trade and supply of electricity have been characterized by high levels of state ownership and natural monopolies, where fixed or capital costs dominate, creating economies of scale that are large in relation to the size of the market and making market entry difficult (Berg and Tschirhart, 1988). In electricity markets, for instance, vertically integrated monopoly utilities would cover the entire value chain from generation to transmission, distribution and sale, with ownership of—and exclusive access to—the relevant infrastructure. In order to limit the exercise of market power and ensure both the affordability and reliability of energy as an increasingly vital commodity, regulators have traditionally intervened with energy policies and regulations aimed at safeguarding the public good. Collectively, such policies make up the design of an electricity market, promoting and, where necessary, balancing various objectives such as energy security, environmental sustainability, and consumer protection.

Over time, advances in the economic theory of regulation and improved understanding of how energy markets operate, combined with the decreasing benefits of economies of scale with the introduction of smaller and more cost-effective gas power generation and advanced information technologies, contributed to several waves of electricity market reforms. In several countries, for instance, the design of electricity markets evolved to promote liberalization and deregulation as a way of encouraging the development of a more diverse and competitive energy industry (Joskow *et al.*, 1983). As government control receded and producers and consumers were given greater latitude in their energy choices, the challenge shifted to ensuring both short-run efficiency—making the best use of existing resources—and long-run efficiency, that is, promoting efficient investment in new resources. Electricity markets have assimilated several new design features to provide reliable electricity at least cost, such as multiple overlapping markets for power, capacity, and ancillary services, sophisticated contracting arrangements and financial products, and new tools to optimize resources and maximize social welfare, such as incentive regulation and locational marginal prices that reflect the marginal value of energy at each time and location (Cramton 2017).

Currently, electricity market designs are again facing substantial pressure to transform. Emergence of disruptive technologies, such as distributed energy resources and digitalization, coupled with ever more stringent environmental policy requirements, are fundamentally changing the landscape in which electricity markets operate. Design of electricity markets, for instance, needs to facilitate the integration of distributed or centralized resources contributing to the efficient provision of electricity services and other public objectives (MIT, 2016). Dramatically increased flexibility through better coordination of existing generation capacities, expanded fast-response generation capacities, and advanced demand response technologies will be critical to accommodate further deployment of variable resources such as wind and solar energy. Currently, however, competitive market designs fail to provide adequate incentives for such flexible resources. Growth in distributed energy resources, such as solar photovoltaic and small-scale wind turbines, on-site energy storage, and electric vehicles, also risks curtailing distribution utility revenue streams as more customers generate their own electricity, threatening a detrimental spiral of utility tariff increases to cover distribution network and other fixed costs, exacerbating the problem through accelerated deployment of distributed resources or even grid defection.

The foregoing challenges have prompted discussion of ratemaking practices that better reflect the spatial and temporal value of electricity and grid services (e.g. time-of-use and scarcity pricing), and increased use of capacity markets to reward firm, dispatchable generation capacity (MIT Joint Program, 2016). Overall, a comprehensive and efficient system of market-determined prices and regulated charges should ideally be based on cost-causation principles, and reflect energy-related services (such as electric energy, operating reserves, firm capacity, and ramp-up capability) and network-related services (such as network connection, voltage control, power quality, network constraint management, and energy loss reduction) (MIT, 2016). Market interconnections with other countries/regions provide the potential to make more efficient choices and to better integrate intermittent and distributed resources.

Challenges have prompted discussion of ratemaking practices that better reflect the spatial and temporal value of electricity and grid services, and increased use of capacity markets to reward firm, dispatchable generation capacity.

In summary, an advanced and well-designed electricity market, combined with advanced digitalization technologies (see Section 4.2), can support various climate change policy instruments and improve the alignment of mitigation objectives, as market-based mechanisms are inherently good at making technology-neutral choices in a cost-efficient manner and providing clear price signals to investors.

Another important feature of many energy markets with substantial repercussions for climate change mitigation are price supports for conventional energy, such as fossil fuel subsidies and cross-subsidies in energy pricing across different sectors. The reduction and eventual elimination of energy subsidies leads to the correction or removal of distortions in costs and prices that inform the decisions of producers, investors, and consumers. In many cases, energy subsidies prolong the life of older technologies and energy-intensive methods of production. Subsidy removal and improved targeting of subsidies reduces the strain on fiscal resources and potentially leads to their improved allocation.

4.1.5 Conclusions

While there is no universal recipe for a choice of a climate policy instrument and experiences and circumstances of every country are unique, Table 4.4 provides our summary of recommended practices and lessons learned ("*do-s*" and "*don't-s*") for different policy categories based on our experience in studying the performances of different options in different regions of the world. In Section 7 we elaborate on particular lessons learned from implementation of Germany's Feed-in Tariff, Renewable Energy Auctions in Brazil, U.S. CAFE/Tailpipe Emission Standards for Vehicles, the Perform, Achieve and Trade energy efficiency program in India, emission trading systems in the European Union (EU Emissions Trading System, or EU ETS) and North America (Regional Greenhouse Gas Initiative, or RGGI), and the carbon tax in Canada's British Columbia.

Table 4.4. DOs and DON'Ts for policy instruments

Policy Category	DO	DON'T
All	Establish clear, transparent and credible framework, on robust regulatory basis Clearly define policy objectives Clearly define consequences of non-compliance Identify (and adjust for) potential policy interactions ex ante Allow for periodic policy review/evaluation and, where necessary, policy adjustment	Pursue multiple or irreconcilable objectives with one policy Allocate insufficient resources to implementation and enforcement Ignore political economy constraints and their bearing on instrument choice
Price controls	Cover as many sectors as possible (preferably all sectors of economy), upstream if needed Establish long-term (5 year or more) price trajectory to provide certainty for investment planning Set price level consistent with targeted externality (e.g. social cost of carbon) Provide additional incentives to R&D Evaluate distributional impacts (on consumers with different income levels) and create targeted support to those in need	Combine with other measures (emission standards, portfolio standards) without careful assessment of overall impact Set unrealistic price paths Change the rules frequently
Quantity controls with trading	Run pilot program (1–2 years) to prepare the system for reliable emissions and activity data Establish credible and long-term (5 year or more) reduction pathways to provide certainty Auction the emission allowances Cover as many sectors as possible (preferably all sectors of economy) Introduce price corridors to reduce price extremes	Over-allocate the allowances Combine with other measures (emission standards, portfolio standards) when coverage only overlaps partly, as that reduces efficiency Set unrealistic targets Change the rules frequently
Quantity controls without trading	Consider compliance options and asymmetrical compliance cost across sectors Consider and, if needed, address impacts on compliance entities For auctions: provide clear and robust consequences for non-compliance For other quantity controls: Limit use as much as possible (e.g. to situations of lacking readiness for economic instruments, or political constraints), and transition to economic instruments when/where possible	Set unrealistic targets Change the rules frequently
Technology standards	Set the levels to require low-carbon technology As experience with new technology is gained, replace with market mechanisms (carbon pricing)	Promote dead-end technologies
Subsidies	Identify contexts where market failures other than pollution externality prevent efficient outcomes, e.g. knowledge spillovers from innovation, and target these Revert to more efficient instruments (carbon pricing) once initial barriers to deployment have been overcome Limit subsidies to providing targeted assistance to vulnerable consumers	Retain subsidy beyond indicated need (e.g. to promote deployment of already competitive technologies; provide access to capital where that no longer is a barrier; etc.)

Fossil Fuel Subsidies in the ASEAN Region

A considerable obstacle to increased deployment of renewable energy in Southeast Asia is the high incidence of fossil fuel subsidies (both for coal and natural gas). Encouragingly, ASEAN countries have embarked on a comprehensive reform agenda, bringing down the volume of fossil fuel subsidies in the region to approximately $17 billion in 2014, less than half the level in 2014 (IEA, 2017d). In Indonesia, for instance, the government eliminated subsidies for gasoline in 2015, and limited subsidies for diesel to IDR 500/liter in 2016. Likewise, electricity tariffs have been gradually increased since 2013, and the share of subsidized customers is expected to decline from 79% in 2016 to 46% (IEA, 2017d). Still, subsidies in place remain significant, and more action is needed to avoid distortions in energy markets and reduce barriers to alternative energy sources.

4.2 Recommendations for Policy Options

Main Takeaways

- For countries with more advanced administrative and technical capacities, we recommend carbon pricing through taxes or quantity controls with tradeable emission permits because they offer the greatest economic efficiency benefits.
- For other countries, we recommend an initial focus on technology-specific policies. As political will and institutional capacities allow, these should gradually be phased out in favor of more cost-effective mitigation instruments.
- Because different policy objectives require their own policy instruments, we recommend that policies adopted to promote climate mitigation should avoid the simultaneous pursuit of other policy objectives, such as development, labor, or industrial policy goals.
- We recommend establishing a clear and transparent policy mix that allows for periodic policy review and adjustments.
- Substantial progress towards emission mitigation goals can be achieved by modernization of electricity market design and a reduction and eventual elimination of fossil fuel subsidies. We recommend continuation of recent efforts at subsidy removal combined with targeted support to low-income consumers.

Because the ASEAN countries represent a wide variety of economies in terms of their level of development and institutional capacity, their choice of policy instruments for GHG emission mitigation depends on administrative and technical capacities to introduce and enforce a particular policy, political support for the desired stringency of emission reductions, and willingness to accept the associated economic cost. Currently, the climate and energy policy portfolios of most ASEAN countries are dominated by a patchwork of energy savings measures and targeted support for renewable energy, embedded in broader—and in many cases aspirational—mitigation strategies. While these policies have shown some positive effects, they are not always cost-effective, nor do they have the scalability to set in motion a broad transition towards a lower-carbon future.

No ASEAN member nation has implemented a carbon price to date, but interest in this highly cost-effective and scalable policy option is growing, with at least one ASEAN country (Singapore) already planning adoption of a carbon tax. For the ASEAN countries with more advanced administrative and technical capacities, we therefore recommend carbon pricing through taxes or quantity controls with tradeable emission permits because they offer the greatest economic efficiency benefits. These instruments are particularly suitable for countries with substantial experience with market-based mechanisms and competitive electricity markets. International experience with such markets is extensive (see Section 7), and capacity building initiatives and guidance on their design and implementation readily accessible from a variety of sources, some of which are already active in several ASEAN countries (e.g. the World Bank Partnership for Market Readiness). As the country analyses in Section 5 show, however, deployment of carbon pricing instruments in the region has been halting, and should therefore be a priority of future policy development for economically more advanced ASEAN countries. Encouragingly, Singapore has already adopted the legislative basis for introduction of a carbon tax in 2019 (see below, Section 5.8.1). This can send a signal to neighboring countries, and offer valuable in-region experiences for other ASEAN countries to study.

For countries that are still in the process of advancing their institutional capacities, we recommend an initial focus on technology-specific policies such as renewable portfolio standards, feed-in tariffs and renewable energy auctions. Feed-in tariffs are already in place in several

ASEAN countries, such as Indonesia, Malaysia, and Thailand, and renewable energy auctions are also gaining more widespread use (USAID, 2017). Such price support measures and fiscal subsidies can be more successful in building coalitions of support for ambitious climate policies, and also in creating domestic supply chains and know-how needed for robust markets in clean technology. At a later stage, however, such targeted support measures should be reviewed and, where political will and institutional capacities allow, gradually phased out as more cost-effective mitigation instruments such as carbon pricing are introduced and scaled up. Recent reductions in fossil fuel subsidies across the ASEAN region have shown that political support can be mustered for policy reforms that increase energy prices. At the same time, thoughtful implementation of policy changes is critical. The political backlash against sudden electricity cost increases due to feed-in tariffs in the Philippines led to the elimination of feed-in tariffs for a majority of renewable energy project types in 2017. The Philippine example shows how politically sensitive energy prices remain and reveals the obstacles governments must overcome to introduce policies affecting energy prices.

Because different policy objectives require their own policy instruments, we recommend that policies adopted to promote climate mitigation should avoid the simultaneous pursuit of other policy objectives, such as development, labor, or industrial policy goals. Combining policy instruments can lower overall efficiency due to adverse interactions and trade-offs. That being said, a policy package with one core policy instrument for each market failure can greatly benefit from supportive planning, market design, and regulatory instruments which promote achievement of that common objective. This is particularly important where complex investment decisions and projects are conditional on multiple enabling factors for successful implementation. A good example is the role of sound electricity market design and transmission and distribution infrastructure planning for the integration of renewable energy sources.

We therefore recommend establishing a clear and transparent policy mix that allows for periodic policy review and adjustments. In many cases, pilot programs (1–2 years) can serve to fine-tune policy design and prepare economic actors for policy compliance; thereafter, however, policies with long time horizons (5 years or more) are recommended to provide planning and investment certainty to market participants. These should be advanced as part of overarching mitigation strategies and accompanied by robust planning processes to ensure consistency across instruments as well as establish the enabling institutional and regulatory frameworks needed for climate policies to achieve their full potential.

Substantial progress towards emission mitigation goals can be achieved by modernization of electricity market design and a reduction and eventual elimination of fossil fuel subsidies. In many cases, energy subsidies prolong the life of older technologies and energy-intensive methods of production. Subsidy removal reduces the strain on fiscal resources and potentially leads to their improved allocation. We therefore recommend continuation of recent efforts at subsidy removal combined with creation of targeted support to low-income consumers.

4.3 Technology Options

Main Takeaways

- Energy transition can be achieved by investments in less-carbon-emitting technologies (like natural gas, wind, solar, hydro, nuclear), technologies that improve energy efficiency (like digitalization), and technologies that enable better network organization and integration of renewables (virtual power plants, microgrids, new transmission lines).
- While wind and solar generation provide attractive options for lowering emissions, switching from coal to natural gas for countries with substantial coal generation (Indonesia, Malaysia, The Philippines, and Vietnam) has a substantial role both for achieving lower carbon content of power generation and for enabling higher penetration of intermittent renewables by serving as a backup capacity.
- The scale of the required energy transformation is large. In a hypothetical scenario of replacing all coal-based generation in the ASEAN region with wind generation, emission reductions would achieve the aggregate unconditional target for 2030 but would fall short of the aggregate conditional target. Thus, emission mitigation should be undertaken not only in power sector, but in all sectors of the economy.
- Wind and solar in the ASEAN region provide a viable option for decarbonization, but these options are limited by their cost, resource availability and power market design.
- Reductions in levelized and integration costs are needed to fully realize the potential for wind and solar generation.
- Power market design should evolve to support the increasing share of variable renewables in electricity generation mix.

Technology options mentioned in the NDCs of the ASEAN countries vary in their level of details from, for example, general declarations about energy efficiency improvements provided in some documents to well-quantified targets for certain power generation technologies like hydropower or wind power provided in other documents. Technology options for reaching the Paris Agreement goals in 2030 depend on the relative costs of these options, the stringency of the required GHG emission reductions up to 2030, and the expected pathways of further reductions after 2030. Estimating relative costs requires detailed modeling of all sectors of the economy to reflect the changes in input and output prices, which is beyond the scope of this report. For illustrative purposes, we provide such estimates for Indonesia and Vietnam in Section 6.

In this section we offer a classification of technology choices for the power generation sector. At the end of this section we offer some insights and recommendations about the technology choices for the ASEAN countries, recognizing heterogeneity of the economies and current utilization of technologies. We also provide a discussion of GHG emission reduction potential and estimate the required generation capacity to replace coal-based power generation. This analysis is intended only as an illustrative example of strategies to meet targeted emission levels, as the ASEAN countries are exploring multiple avenues of emissions reduction, including energy efficiency measures and improved public transportation.

The list of technology options for the power generation sector is extensive. We categorize the options into five groups (see Table 4.5). In *Tier I* we include options related to building or retrofitting power plants to provide lower-carbon emitting generation options than the current fleet. For many ASEAN countries it means switching from unabated coal-based generation. The options vary by their capital-intensity, maturity and scale. Relatively lower capital-intensive options in this cluster include renewables like wind, solar and small-scale hydro. Another option is natural gas, a fuel that is beneficial for countries currently relying on coal but that locks in the long-lived energy infrastructure and may interfere with more stringent targets in the future. Other options in this category are also important for emission mitigation, but they are limited either by geography (like geothermal and pumped hydro) or by their maturity and the required scale to satisfy the power needs at a country level (like waste and tidal/wave). Capital-intensive options include nuclear power, large hydropower, and carbon capture and storage (CCS) technology. These capital-intensive projects require substantially longer planning processes and government support.

Table 4.5. Typology of Technology Options

Tier	Technology Category	Examples
I	**Building and Retrofitting Power Plants**	**Less Capital-Intensive** • Natural gas • Wind and solar • Renewables more limited by geography (e.g. small-scale hydro, pumped hydro, waste, geothermal, and tidal/wave) **More Capital-Intensive** • Nuclear and large hydro
II	**Improving Efficiency and Optimization**	• Higher efficiency power plants (e.g. ultra-super critical coal plants) • Higher utilization of currently installed lower-carbon generation technologies • Digitalization applied to both the production and consumption sides
III	**Enhancing Market and Network Organization**	• Options to enable distributed generation • Time-of-day pricing • Improved integration of renewables (e.g. new transmission lines, virtual power plants, microgrids, tools for better citing and forecasting of wind and solar farms) • Battery energy storage
IV	**Options with Potential Sustainability Issues**	• Large scale biomass-based options
V	**Options for Future Consideration**	• Carbon capture and storage (CCS) • Advanced nuclear • Advanced energy storage (e.g. generating hydrogen with renewable power)

In *Tier II* we group the options for improved efficiency. This tier includes the construction of more efficient power plants (e.g., ultra-super critical coal plants) relative to the current generation fleet and higher utilization of the currently installed lower carbon generation technologies. *Tier II* also includes digitalization, both on the production side (related to the collection of information on new and existing power plants to increase efficiency and to allow greater penetration of renewables) and on the consumption side (related to the collection of information on customers to better serve their needs through improved resource allocation).

The options in *Tier III* relate to technologies that enhance market and network organization (e.g., enabling distributed generation, time-of-the-day pricing, etc.), and include options for an improved integration of renewables (e.g., new transmission lines, virtual power plants, microgrids, tools for better citing and forecasting of wind and solar farms to maximize their utilization).

While we consider options in *Tiers I–III* to be better suited to the ASEAN countries, two more categories are worth monitoring to re-assess their viability as additional information comes in from pilot and small-scale projects. *Tier IV* contains the options with potential sustainability issues, such as biomass-based options with unresolved concerns about scalability, land-use change impacts, transportation costs, and impacts on food prices[3]. In *Tier V,* we include options that may be more attractive and economical in the future, such as energy storage. Viable energy storage may arise in the form of batteries or as the capability to generate hydrogen with renewable power. A clear message regarding technology options, however, is that coal-based power becomes even riskier because a CCS option is still uneconomic, and future emission targets are likely to increase in stringency.

Renewable energy technology options listed in *Tier I* continue to mature. Their costs continue to fall, making renewable energy increasingly competitive. As mentioned in Section 4.1, policies to support wind and solar are increasingly focused on bidding for long-term contracts. While there is an expected proliferation of smaller-scale projects like solar and wind farms, utility-scale projects are projected to dominate electricity supply (IEA, 2017b). At the same time, non-utility companies are using new technologies (listed in *Tiers II* and *III*) to compete with utilities. Small producers are investing in solar and wind farms that are typically only tens of megawatts (MW) in size compared to traditional fossil-fuel plants of several hundred MW. The expanding role of small players requires market design changes to provide revenue streams to sources that contribute to the adequacy of power supply, like capacity payments and payments for balancing services.

Technology option evolution depends on power sector policies. In countries where the regulatory model does not encourage sophisticated integration of distributed generation, intermittent renewables will face substantial challenges to expand. Such rigidity is at odds with the evolving trends in many power markets such as a growth in intermittent renewables and increased digitalization of energy assets. The technology options in *Tier III* will help power system to accommodate greater complexity and connectivity. Another aspect of intermittent renewables is that their value can decline substantially as they reach larger shares of total generation (Hirth, 2013), which again calls for more sophisticated regulatory models that encourage flexibility and integrated planning.

Intermittent renewables will face substantial challenges in countries where the regulatory model does not encourage sophisticated integration of distributed generation.

The potential for GHG emission reduction through *Tier I* technologies can be illustrated with a hypothetical example of removing coal-based generation from the electricity mix. While we do not advocate for a complete replacement of coal-based generation in a short period of time, the impact of a technology choice can be dramatized by our illustrative example that shows the magnitude of a potential change. Below we perform a simple evaluation of GHG emission reduction by exploring two extreme choices: replacing coal with natural gas or replacing coal with wind (a calculation for replacing coal with solar power leads to the similar results).

Coal is the most carbon-intensive fossil fuel with a carbon content of 3.96 tCO_2/toe. Natural gas has a carbon content of 2.35 tCO_2/toe, which is about 60% of the carbon content of coal (BP, 2015). When producing electricity, natural gas has the additional advantage of a higher efficiency (i.e., the ratio of energy output to energy input) of generation. According to IEA (2017b), efficiency of the current global fleet of natural gas power plants is around 43%-50% while coal generation efficiency is about 32–40%.[4] For the ASEAN region, historic and projected efficiencies of generation are presented in Table 4.6. Efficiency of coal-based generation

3 While several ASEAN countries use biomass and waste to energy conversion, sustainability and scalability of these options are an area of further investigations.

4 The 2017 IEA World Energy Outlook reports power generation and fuel use for the fleet of natural gas power plants for 2016 consistent with an average efficiency of 48% in the United States and 43% in the ASEAN region. For the coal power plants fleet for 2016, the efficiency is 36% in the United States and 32% in the ASEAN region (IEA, 2017b).

is projected to increase from the current 32% to 35% in 2030. Efficiency of natural gas-based generation is projected to increase from the current 43% to 46% in 2030. While oil- and biomass-based generations have lower efficiencies, their relative contributions to total generation is small (see Figure 3.2). Emission reduction estimates for a switch from coal to natural gas depend not only on the efficiencies of coal power plants, but also on the efficiency of the natural gas fleet that would replace them. We provide emission reduction estimates both for the current efficiency of the ASEAN natural gas-based fleet (43%) and the most efficient (64%) natural gas turbine currently on a market.[5]

Another parameter affecting calculations of capacity requirements of a switch away from coal-based generation is the capacity factor, which shows a percentage of the hours in a year when a plant is operating at full capacity. While typical calculation for new projects usually assume an 85% capacity factor (EIA, 2018), the fleet capacity factors are close to 50–55% for coal and natural gas generation in USA and China. For ASEAN, in Table 4.7 we provide capacity factors for different generation types. IEA (2017b) projects coal capacity factors to increase while natural gas capacity factors decrease likely in response to projected relative prices of coal and natural gas in the ASEAN region.

Table 4.6. Efficiency of ASEAN Electricity Generation

	2000	2015	2016e	2025	2030
Coal	34.2%	32.1%	32.1%	34.5%	35.2%
Oil	33.2%	33.1%	33.1%	31.4%	30.2%
Gas	37.2%	42.9%	42.8%	44.7%	45.9%
Bioenergy	12.6%	17.8%	17.9%	23.6%	24.9%

Source: Calculated from IEA (2017b).

Table 4.7. Capacity Factors of ASEAN Electricity Generation

	2015	2016e	2025	2030
Coal	57%	56%	58%	61%
Oil	14%	16%	10%	11%
Gas	50%	49%	45%	43%
Hydro	32%	35%	36%	37%
Bioenergy	18%	23%	42%	48%
Wind	19%	16%	29%	29%
Geothermal	73%	75%	76%	77%
Solar PV	13%	11%	16%	17%

Source: Calculated from IEA (2017b).

With lower capacity factors for natural gas generation, a larger number of gas turbines is needed to replace a certain amount of coal generation. We provide an estimate for both 55% and 85% capacity factors. As discussed in Section 3 (and shown in Figure 3.2), we estimate that the total coal-based generation in 2030 in the ASEAN countries will be about 743,219 GWh. Table 4.8 provides an estimate of the impacts on GHG emissions and capacity requirements if the coal generation fleet were retired and replaced with lower-carbon natural gas generation. We estimate a reduction of about 426–537 $MtCO_2$, depending on natural gas generation efficiency, when all coal power generation is replaced with natural gas generation. Emission reductions from the replacement of coal with natural gas are close to what

5 The most efficient natural plant with three 7HA turbines was verified to have 63% efficiency (Guiness, 2018) and GE reports 64% efficiency for its most advanced (class 9HA) natural gas turbine (GE, 2018a).

is needed for the aggregate ASEAN emission reduction with the unconditional targets (415 $MtCO_2$) but not enough for meeting conditional reductions (899 $MtCO_2$). This is driven by the fact that despite being a relatively clean fuel, natural gas still emits a substantial amount of carbon.

With a capacity factor of 85%, about 100 GW of natural gas-based generating capacity would be needed to be employed in the ASEAN countries. Considering a 100 MW natural gas turbine, this needed capacity corresponds to about 998 new natural gas turbines in the ASEAN countries. If the natural gas fleet in the ASEAN countries were to be run in a similar way as in the USA and China, then a lower capacity factor for natural gas generation would increase the requirement for installed capacity. For example, a (lower) capacity factor of 55% would increase the capacity requirements to 154 GW, which is equivalent to about 1,543 natural gas turbines of 100 MW each.

We also assess the impacts of meeting emission reduction goals in the ASEAN region using wind power only. Table 4.9 provides estimates of targeted emission reductions, the corresponding requirements for wind capacity, and equivalent number of 2 MW and 4 MW wind turbines[6]. The current capacity factors for wind in the ASEAN region are relatively low (see Table 4.7), but they are expected to improve. IEA (2017b) estimates an increase in capacity factor for the average wind fleet in the ASEAN region to about 30%. Individual wind farm projects are expected to achieve capacity factors as high as 45%.

With lower capacity factors of wind generation, the larger number of wind turbines is needed to replace a certain amount of coal generation. We present our estimates under both 30% and 45% capacity factor assumptions for wind generation. We stress again the simplified nature of this calculation because it ignores price responses and assumes that wind generation replaces coal generation while in reality all types of generation will be affected. Our illustrative example is still useful to understand the magnitude of such heroic assumption as replacement of coal generation with wind.

The use of more highly utilized turbines with a 45% capacity factor[7] would require only two-thirds the additional wind capacity, or about 25,596 4-MW turbines to meet unconditional targets and 55,451 4-MW turbines to meet conditional targets. Regardless of the assumptions, this example shows a dramatic increase in the wind power investments.

Improvements in the efficiency of coal-based generation offer another avenue for CO_2 emission reductions. GE estimates that coal plants can be made 3 percentage points more efficient through turbine and boiler upgrades and an additional 1.5 percentage points more efficient through digitalization (i.e., use of software for greater reliability and more efficient operations) (GE, 2016, 2017). Table 4.10 shows the results for a hypothetical case in which the entire fleet of coal power plants improves in efficiency by 4.5 percentage points from the current 32.1% in the ASEAN region (IEA, 2017b) to 36.6%. Efficiency improvements lead to a reduction by almost 100 $MtCO_2$.

Table 4.8 also lists the estimated emissions reduction in 2030 for the ASEAN countries as 415 $MtCO_2$ in the case of unconditional targets and 899 $MtCO_2$ in the case of conditional targets (see also Table 2.1). Comparing these numbers with the emission reduction potentials leads to an observation that even if all coal-based generation in ASEAN is replaced with

6 A current generation of onshore wind turbines has capacities in the 1–4 MW range with a typical size of 2.5–3 MW. Offshore wind turbines are larger with the current sizes for advanced designs up to 8 MW and the turbines of 12–15 MW are under development.

7 For the aggregate calculation, an average capacity factor for the whole fleet of wind generation is needed to be considered rather than a capacity factor of an individual turbine.

natural gas or renewables-based generation, the conditional Paris Agreement goals would not be met. A switch to natural gas provides a substantial reduction of 424 $MtCO_2$, which is about the same as the 415 $MtCO_2e$ unconditional target. Replacing all coal-based generation with wind generation would be more than enough to meet the unconditional target for ASEAN but not enough to meet its conditional target. Still, this replacement leads to a reduction of 764 $MtCO_2$, about 85% of the needed 899 $MtCO_2e$ reduction.

Even if all coal-based generation in ASEAN is replaced with natural gas or renewables-based generation, the conditional Paris Agreement goals would not be met.

Table 4.8. Impacts of replacing coal generation with natural gas generation

	Replace ALL Coal-Fired Generation with Natural Gas
Magnitude of replacement	
2030 Baseline coal-fired generation (GWh)	743,219
Emissions reduction potential	
43% natural gas generation efficiency ($MtCO_2e$)	426
64% natural gas generation efficiency ($MtCO_2e$)	537
Natural gas capacity factor: 55%	
Natural gas capacity (GW)	154
Number of 100 MW gas turbines	1,543
Natural gas capacity factor: 85%	
Natural gas capacity (GW)	100
Number of 100 MW gas turbines	998

Table 4.9. Emission reduction goals and the corresponding requirements for wind capacity

	Unconditional	Conditional
Gap magnitude		
Targeted emissions reduction ($MtCO_2e$)	415	899
Renewables capacity factor: 30%		
Renewables capacity (GW)	154	333
Number of 4 MW wind turbines	38,394	83,176
Number of 2 MW wind turbines	76,788	166,353
Renewables capacity factor: 45%		
Renewables capacity (GW)	102	222
Number of 4 MW wind turbines	25,596	55,451
Number of 2 MW wind turbines	51,192	110,902

Table 4.10. CO_2 displaced under alternative scenarios in ASEAN region in 2030

Scenario	Description	CO_2 displaced ($MtCO_2$)
Wind	Replace all coal generation with wind	764
Gas 64%	Replace all coal generation with natural gas at 64% efficiency	537
Gas 43%	Replace all coal generation with natural gas at 43% efficiency	424
Coal digit	Improve coal plant efficiency by 4.5 points from 32.1% to 36.6%	94
Unconditional	Replace coal generation with wind to meet unconditional targets	415
Conditional	Replace coal generation with wind to meet conditional targets	899

Figure 4.1 shows the results for different options. These illustrative calculations convey that major shifts in a choice of generating technology move the ASEAN countries significantly toward their emission reduction goals, but in many cases the actions that target only the power generation sector would not be sufficient for meeting the Paris Agreement goals. Recall again that these rough estimates are obtained under the extreme assumptions that all emission reductions take place in the power generation sector exclusively and the whole fleet of coal-based generation is either replaced or improved. Mitigation action most likely will employ a set of different options in different sectors of economy. For more elaborate estimates at a country level, we refer to the analysis in Section 6.

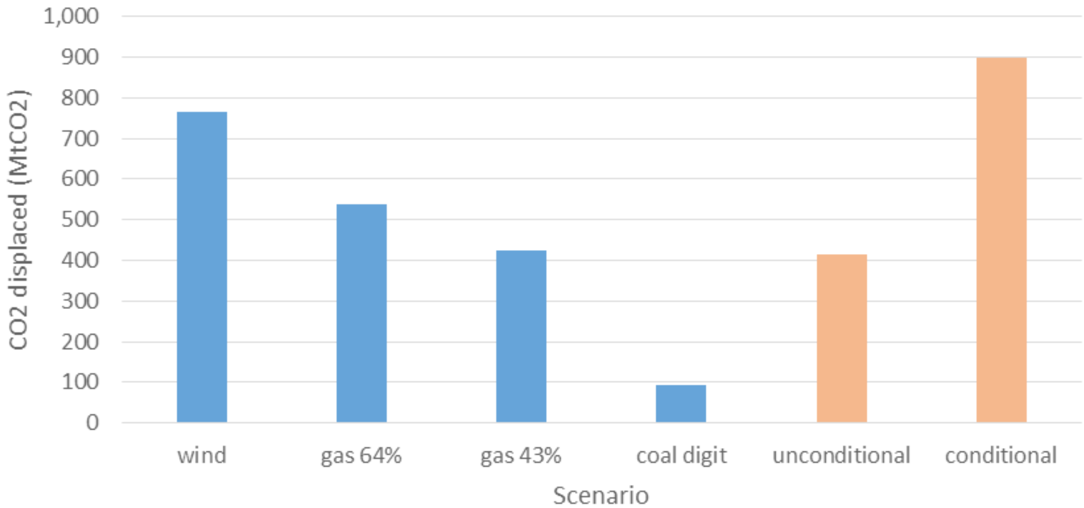

Figure 4.1. CO_2 displaced under alternative scenarios in ASEAN region in 2030

4.4 Recommendations for Technology Options

Main Takeaways

- Policy makers should incentivize emission reductions from all sources of energy technologies rather than favor any particular technology. Considerable uncertainty about future costs and integration challenges necessitates a flexible approach.
- Intensify preparation for the integration of higher shares of non-dispatchable technologies such as wind and solar.
- While wind and solar generation provide attractive options for lowering emissions, a switch from coal to natural gas promotes lower-carbon power generation and enables higher penetration of intermittent renewables by serving as backup capacity.
- Explore options for nuclear and CCS technologies—although natural gas is currently a viable lower-emitting alternative to coal, future emission reduction targets are likely to be more aggressive.
- Wider use of technologies that enable energy efficiency improvements, both in the construction of more efficient power plants and through the use of digital technology to improve existing processes and incorporate new methods of energy transformation, delivery and usage.
- Monitor technological progress and adjust the options under consideration as new technologies become more economically feasible.

Numerous technology options are available for GHG emission mitigation. We categorize the most promising options into three clusters. In *Tier I* we include options related to building or retrofitting power plants to provide lower-carbon emitting generation options than the current fleet. For many ASEAN countries it means switching from unabated coal-based generation. The options vary by their capital-intensity, maturity and scale. They include wind, solar, natural gas, hydro, geothermal, and waste. In *Tier II* we group the technology options that lead to an improved efficiency (more-efficient turbines, digitalization), both on the production and on the consumption sides. The options in *Tier III* relate to technologies that enhance market and network organization (e.g., enabling distributed generation, time-of-the-day pricing, etc.), and include options for an improved integration of renewables (e.g., new transmission lines, virtual power plants, microgrids, tools for better citing and forecasting of wind and solar farms to maximize their utilization).

Despite substantial progress in bringing down costs of certain types of low-carbon power generation, the considerable uncertainty about the future costs of different technologies and the challenges for their integration to the system necessitates a flexible approach. We recommend that policy makers incentivize emission reductions from all sources of energy technologies rather than favor any particular technology.

As wind and solar options become more competitive, they offer a valuable option for emission reduction. The ASEAN countries are still at low levels of penetration of intermittent renewables, and therefore, their integration into the power system is currently relatively simple. However, challenges may arise with higher levels of penetration. We recommend that policy makers, regulators, market and network operators, utilities, and other players intensify preparations for the integration of higher shares of non-dispatchable technologies such as wind and solar.

While coal power is the cheapest and most reliable energy option in many ASEAN countries, natural gas provides a viable alternative in order to reduce GHG emissions and local air pollutants. However, because future emission reduction targets (for the period beyond the current Paris pledges) are likely to be more aggressive, we recommend, in addition, exploring options for nuclear and CCS technologies, keeping in mind that these capital-intensive projects require longer planning timelines and extensive government support.

We also recommend a wider use of technologies that enable energy efficiency improvements, both in the construction of more efficient power plants and through the use of digital technology to improve existing supply- and demand-side processes and incorporate new methods of energy transformation, delivery and usage processes such as Microgrid, Virtual Power Plant, storage and distributed energy management.

Decision-makers should monitor the latest advances in technologies that enhance market and network organization (e.g., enabling distributed generation, time-of-the-day pricing, etc.) and consider options for the improved integration of renewables.

Finally, we emphasize that other technologies may become more attractive in the future. Possible options include energy storage as well as the production of hydrogen with renewable power and its consequent use for energy needs. Therefore, we recommend monitoring technological progress and adjusting the options under consideration as new technologies become more economically feasible.

5 Country-level Analysis

In this section, we provide estimates of the emissions gap between the Baseline scenario trajectories and NDC pledges for each ASEAN country. We perform this analysis by (1) projecting each country's Baseline emissions based on historical energy, economic, and emissions data and (2) translating each country's NDC commitments into economy-wide emission targets. We then calculate the emissions gap as the difference in GHG emissions between the Baseline and NDC-pledged paths.

Our generalized methodology to establish economy-wide Baseline emission projections considers emissions from the energy (fuel combustion), industrial processes, agriculture, and waste sectors. To determine energy emissions, we first estimate CO_2 from combustion by projecting energy intensity of GDP from 2016 to 2030[1] using the historical, average annual growth rate in energy intensity of GDP from 2000 to 2015[2], calculated with data on total primary energy supply from IEA (2017a, 2017b) and real GDP from IMF (2017). With a growth rate based on historical and projected GDP data for 2000 to 2022 (IMF, 2017), we develop GDP projections to 2030 and apply them to the projected energy intensity of GDP to estimate total future energy supply. Then, assuming that the energy mix remains constant in the Baseline scenario, we apply CO_2 emission factors (Table 5.1) to the future supply of coal, oil, and natural gas to estimate CO_2 emissions from the energy sector.

Table 5.1. Emission factors

	Emission Factors (tCO_2/toe)
Coal	3.96
Oil	3.07
Natural gas	2.35

Source: BP (2015)

To calculate CH_4 and N_2O emissions from the energy sector, we source historical emissions from country reports, and project non-CO_2 energy emissions at the rate of change of forecasted natural gas production (IEA, 2017b). To calculate non-energy emissions (i.e., emissions from industry, agriculture and waste), we source historical emissions from country reports and increase CH_4 and N_2O emissions at the population growth rate (UN, 2017), and non-energy CO_2 and major industrial GHGs at the GDP growth rate. We exclude LULUCF emissions from our analysis to focus attention on the role renewable energy and energy efficiency technologies and policies can play in supporting NDC commitments. Our step-by-step methodology and a compilation of country specific adjustments are included in Appendix B.

Some countries provide information in their NDCs about their projections of the economy-wide emissions in the Baseline scenario and under their intended policies. Where available, we include the corresponding information from the NDCs. For those countries that do not report economy-wide emission targets in their NDCs, we provide only our estimates of economy-wide targets associated with their stated goals. Additionally, for some countries we discuss an alternative emission trajectory reflecting generation profiles presented in country reports.

In contrast to other multi-country gap analyses (see PBL, 2017), we have actively engaged with country officials to initiate an open dialogue on our methodology and assumptions.[3] We have also created country-specific Excel workbooks with relevant historical data, growth rates, and resulting projections so that users can explore the effects of alternative assumptions. These

1 Projections extend to 2035 for Brunei Darussalam in accordance with its NDC targets.

2 IEA (2017a) does not report TPES for Lao PDR, so historical energy and emissions in Lao PDR for 2005–2014 is sourced from ACE (2017).

3 MIT researchers convened with representatives from ACE and the energy ministries of eight ASEAN Member States in Manila in September 2017.

workbooks are available upon request. By preserving transparency in our work, we hope to encourage further collaboration between the ASEAN countries and international community in estimating, measuring, and ultimately achieving NDC targets.

Countries are reviewed in alphabetical order. We conclude each country-specific discussion with an overview of NDC-reported strategies and policies to meet commitments. Further detail on each country's existing renewable energy policies and future renewable energy targets (beyond the NDCs) is provided in the ASEAN Renewable Energy Policies report (ACE, 2016). For reference, a compilation of official NDC pledges is provided in Appendix A. A step-by-step methodology with country-specific adjustments is provided in Appendix B. Appendix C illustrates each country's energy intensity of GDP and emission intensity of energy supply. Finally, a comparison of non-CO_2 energy emissions from alternative sources is in Appendix D.

5.1 Brunei Darussalam

Figure 5.1.1. Map of Brunei Darussalam

Brunei Darussalam is a small nation on the island of Borneo in Southeast Asia. Brunei Darussalam shares its south, east, and west-facing borders with Malaysia while its northern border opens to the South China Sea. About 75% of the Brunei Darussalam's total land area is covered by tropical rainforest. To conserve this ecosystem, Brunei Darussalam has committed to protect 58% of its total land area through the "Heart of Borneo" initiative, a joint undertaking of Brunei Darussalam, Malaysia, Indonesia, and international partners.

According to UN (2017), Brunei Darussalam had a population of 417,542 people in 2015, or 0.07 % of the total population in the ASEAN region. Brunei Darussalam's population grew an average of 1.51 % annually from 2000 to 2015 (compared to the ASEAN rate of 1.27%) and is projected to grow at an average annual rate of 0.97% from 2016 through 2035 (compared to the ASEAN rate of 0.85%).

In 2014 the GDP of Brunei Darussalam was 18.6 billion 2010 Brunei dollars (12.9 billion USD)[4]. The country experienced an average annual growth rate of 0.87% from 2000 to 2015 (IMF,

4 A comparison in US dollars (USD) is provided for GDP in current prices (i.e., in a year of the quote).

2017), though this rate reflects an economic downturn in 2012. However, based on IMF historical and projected data for 2000 to 2022, we adopt a 2.39% average annual growth rate of GDP for 2016 to 2035.

Below we present our projections for energy supply, electricity generation, and GHG emissions in Brunei Darussalam. We also describe Brunei Darussalam's NDC targets and highlight some of the technologies and policies Brunei Darussalam has referenced to meet its commitments. Tables summarizing modeling assumptions for Brunei Darussalam are included at the end of this section.

Data on TPES and generation in Brunei Darussalam for years 2000 to 2015 is sourced from IEA (2017a). A reduction in TPES and electricity generation after 2015 is driven by the impact of low prices for energy exports on the economic activities. We consider it as a temporary shock with Brunei Darussalam returning to its longer-term growth trajectory after 2022. We project that TPES in 2035 will total 4,365 ktoe with 79% from natural gas, 21% from oil, and negligible amounts from renewable sources. Electricity generation is projected to reach 7,447 GWh in 2035 with a generation mix of 99% natural gas and 1% oil.

Data for GDP for Brunei Darussalam (in 2010 Brunei dollars) is taken from IMF (2017). Historic changes in Brunei Darussalam's energy intensity of GDP are substantially affected by oil and natural gas prices. Despite the substantial changes, the annual variations of energy intensity of GDP are located around the flat long-term trend from 2000 to 2015. While Brunei Darussalam is like to continue to be impacted by large changes in oil and natural gas prices, we focus on a longer-term trajectory and consider that the energy intensity of GDP in Brunei Darussalam will show little change on average and reach 146.3 ktoe per billion 2010 Brunei dollars in 2035. See Appendix C for figures illustrating energy intensity of GDP as well as emission intensity of TPES over time.

In the Baseline scenario, Brunei Darussalam is projected to emit 14.3 $MtCO_2e$, excluding LULUCF emissions in the year 2035, with emissions from fossil fuel combustion contributing 98.4% of total GHG emissions. In its NDC, Brunei Darussalam pledges to reduce its energy intensity of GDP by 45% in 2035 relative to 2005, which corresponds to a total GHG emission target of 10.3 $MtCO_2e$ in 2035.

Brunei Darussalam cites multiple policy objectives in support of its energy intensity goals including electricity tariff reform, building energy efficiency standards and ratings, fuel economy regulations, and financial incentives to adoption of energy-efficient products. Potential technology avenues under consideration are increased use of energy efficient streetlights, adoption of building energy management systems, and the replacement of open cycle power plants with combined-cycle or combined heat and power plants.

Brunei Darussalam intends to meet its renewable generation objectives through solar power and waste-to-energy generation. According to Brunei Darussalam's NDC, the Tenaga Suria Brunei (TSB) solar power plant currently provides 1,600 MWh per year, and a three-year study on six types of solar cells was conducted at the facility in 2010 to 2012 to support further expansion of solar generation. Additionally, the Energy Department in Brunei Darussalam is investigating the feasibility of a 10–15 MW waste-to-energy facility. Wind power, hydropower, and tidal power are also being considered for generation in the longer term.

Brunei Darussalam makes the additional pledge to reduce CO_2 emissions from morning peak-hour vehicle use by 40% relative to a 2035 BAU scenario by improving vehicle fuel efficiency and promoting transportation by bus, walking, and cycling. Brunei Darussalam's Land Transport White Paper identifies several transport policy recommendations to increase the share of public transport trips from 1% to 22% of trips by 2035. The report also recommends development of a public transit hub in capital city Bandar Seri Begawan, policies to promote hybrid and electric vehicles, creation of fuel economy regulations, and review of existing fuel subsidies.

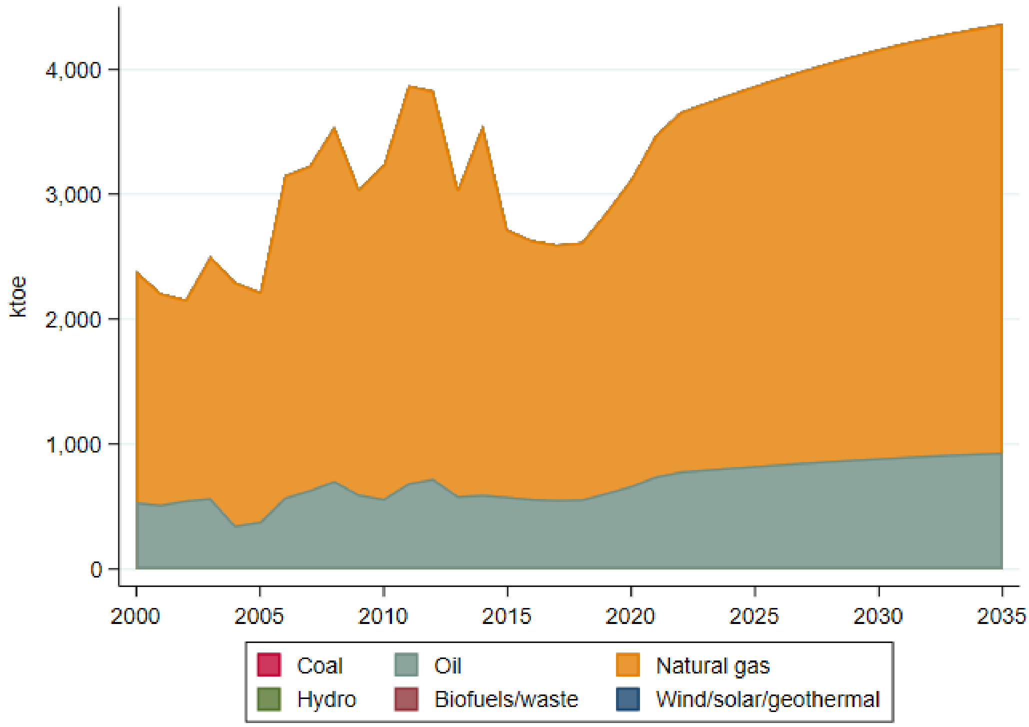

Figure 5.1.2. Brunei Darussalam Total Primary Energy Supply (TPES)

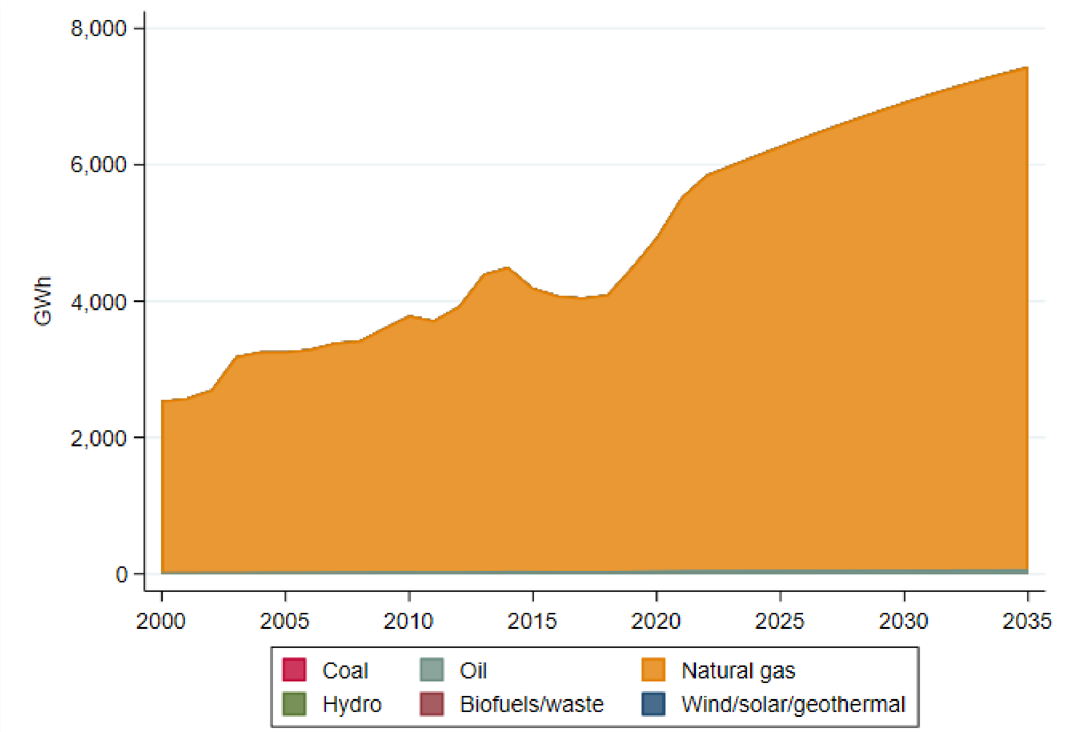

Figure 5.1.3. Brunei Darussalam electricity generation

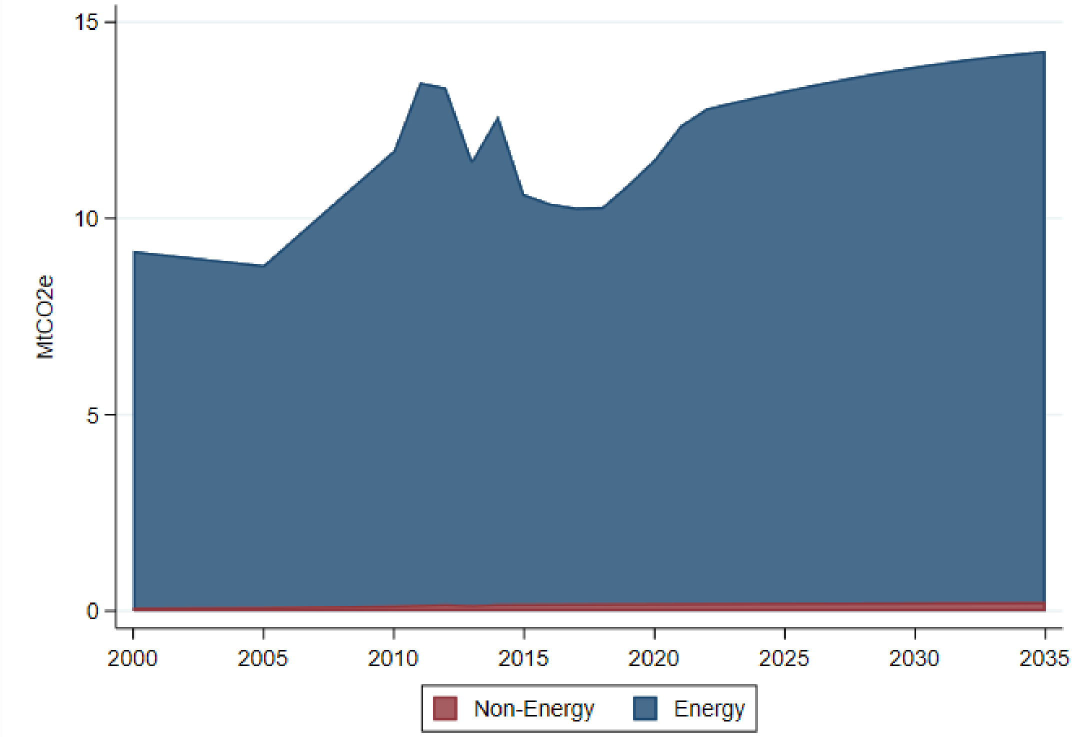

Figure 5.1.4. Brunei Darussalam sectoral emissions

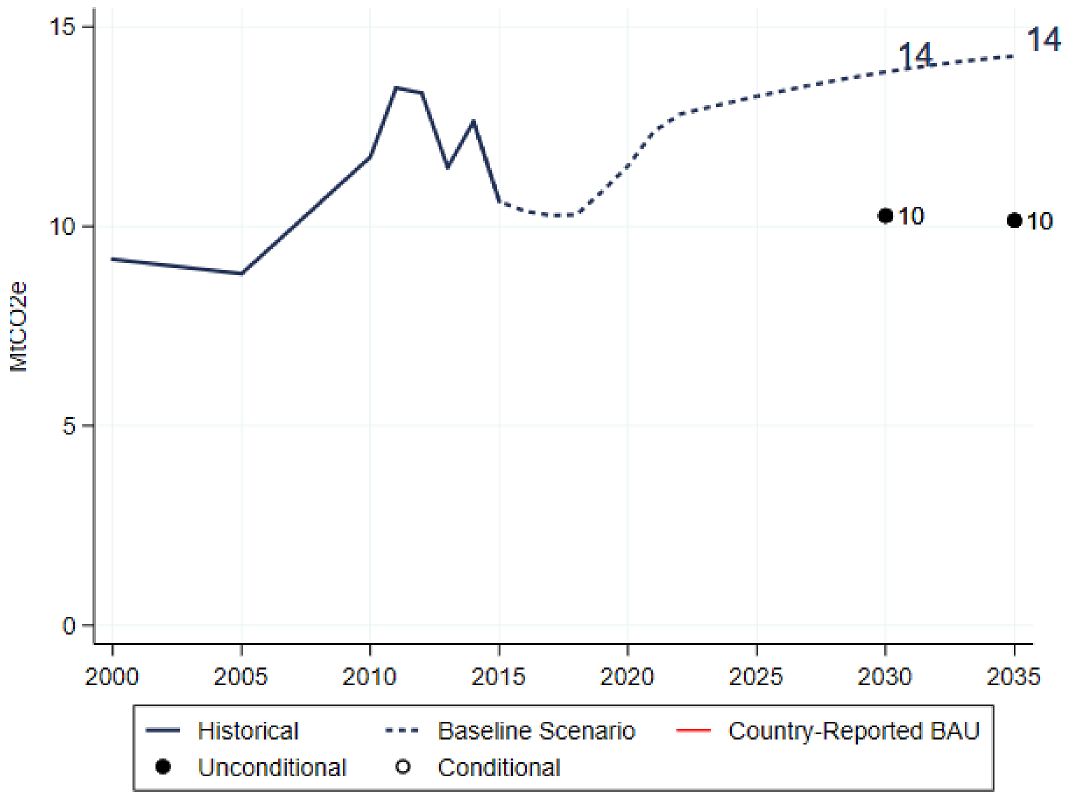

Figure 5.1.5. Brunei Darussalam total emissions

Table 5.1.1 Policies and technologies declared in Brunei Darussalam's NDC

Type	NDC Reference
Declared Policies	Electricity Tariff Reform (2012)
	Energy White Paper (2014)
	Land Transport White Paper
	Energy Efficiency and Conservation (EEC) Building Guidelines
	Green Building Initiative
Declared Technologies	Alternative energy generation (solar power, waste-to-energy)
	Combined-cycle or combine heat and power plants
	Technologies to reduce flaring and venting during gas extraction
	Energy-efficient buildings (adoption of demand controllers, Building Automation Systems, and Building Energy Management Systems)
	Public transit/traffic management (Expansion of bus fleet, intelligent transport systems)
	Fuel-efficient and hybrid/electric vehicles
	Energy-efficient streetlights

Table 5.1.2. Fuel shares and generation ratios for Brunei Darussalam

	Coal	Oil	Natural gas	Hydro	Geothermal/ solar/wind	Biofuels/ waste
2015: TPES Share	--	0.21	0.79	--	0.00	--
2015: Ratio - generation to TPES (GWh/ktoe)	--	0.07	1.95	--	11.63	--
Source: Calculations using IEA (2017a)						

Table 5.1.3. Projected growth rates for Brunei Darussalam

	Average Annual Growth Rates
GDP (2023–2035)	1.36%
TPES per GDP (2016–2035)	0.01%
Population (2016–2035)	1.29%

Source: Calculations using IEA (2017a), IMF (2017), and UN (2017)

5.2 Cambodia

Figure 5.2.1. Map of Cambodia

Cambodia is a nation on the Indochina Peninsula in Southeast Asia. The country spans the delta of the Mekong River, on which the capital city, Phnom Penh, is situated. Cambodia shares borders with Vietnam, Lao PDR, and Thailand and faces the Gulf of Thailand to the southwest.

According to UN (2017), Cambodia had a population of 15.5 million people in 2015, or 2.45% of the total population in the ASEAN region. Cambodia's population grew an average of 1.64% annually from 2000 to 2015 (compared to the ASEAN rate of 1.27%) and is projected to grow at an average annual rate of 1.29% from 2016 through 2030 (compared to the ASEAN rate of 0.92%).

In 2012 the GDP of Cambodia was 34.9 trillion 2000 Cambodian riels (18.2 billion USD). The country experienced an average annual growth rate of 7.73% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 6.86% average annual growth rate of GDP for 2016 to 2030.

Below we present our projections for energy supply, electricity generation, and GHG emissions in Cambodia. We also describe Cambodia's NDC targets and highlight some of the technologies and policies Cambodia has referenced to meet its commitments. Tables summarizing modeling assumptions for Cambodia are included at the end of this section.

Data on TPES and generation in Cambodia for years 2000 to 2015 is sourced from IEA (2017a). We project that TPES in 2030 will total 12,379 ktoe with 61% from biofuels and waste, 28% from oil, 8% from coal, 2% from hydro, and negligible amounts from other renewables. Electricity generation is projected to reach 8,178 GWh in 2030 with a generation mix of 50% coal, 44% hydro, 5% oil, and 1% biofuels and other non-hydro renewables.

Data for GDP in Cambodia (in 2000 Cambodian riels) is taken from IMF (2017). Based on historical trends from 2000 to 2015, we project that energy intensity of GDP in Cambodia will show an average annual decline of 2.7% and reach 0.106 ktoe per billion 2000 riels by 2030. See Appendix C for figures illustrating energy intensity of GDP as well as emission intensity of TPES over time.

In the Baseline scenario, Cambodia is projected to emit 15.7MtCO_2e from the energy sector in the year 2030. Energy emissions contribute 32% of total GHG emissions (as in Figure 5.2.4) but to calculate policy emission targets, we use a Baseline scenario (illustrated in Figure 5.2.5) with energy-related emissions only to align with the exclusion of agricultural emissions (responsible for 98% of the country's non-energy GHG emissions) in Cambodia's NDC. In its NDC, Cambodia pledges to reduce total GHG emissions by 27% in 2030 relative to its BAU conditional on international financial support, which yields a conditional GHG emission target of 11.2 MtCO_2e in 2030. No unconditional target is specified, so we assume Baseline emissions in the absence of technical and financial support.

In comparison, Cambodia reports an expected BAU emission level of 11.6 MtCO_2e inclusive of emissions from energy, manufacturing, and transport sectors with a resulting emissions target of 8.5 MtCO_2e. We derive historical emission levels for the year 2000 as the sum of emissions from energy and waste as reported by Cambodia's 2nd National Communication to the UNFCCC. The two BAU trajectories largely follow a parallel path with the exception of a sharp increase in MIT's Baseline calculations in 2012–2015, the result of an increase in coal-fired electricity generation from 37 GWh in 2012 to 2,128 GWh in 2015. While the ASEAN Center for Energy (ACE, 2017) reports a similar increase in coal use in Cambodia in this time period, fluctuations in annual emission levels are not shown in the country-reported BAU because of limited data availability.

Cambodia's NDC proposes several technology avenues to meet both its emission and development goals. The country lists the development and use of renewable energy as a priority action and intends to develop a national grid of connected energy sourced from solar, hydro, biomass and biogas—in addition to off-grid electricity, such as solar homes—in order to increase the country's electrification ratio from its 2015 level of 65% (ACE, 2017). Additionally, Cambodia intends to increase the use of renewable energy in the manufacturing industry, namely in its garment factories, rice mills, and brick kilns. Energy efficiency measures in factories, motor vehicles, and buildings are also being promoted. Smaller projects in line with development goals include increasing access to energy efficient cook stoves, biodigesters, and solar lamps in the residential sector to lower rural areas' emission footprint while providing greater access to electricity. An organizational foundation to implement these actions is described in Cambodia's Climate Change Strategic Plan for 2014–2023.

In developing its Climate Change Financing Framework, the government of Cambodia estimated that public expenditure on climate change response was equivalent to 1.31% of national GDP in 2012 (RGC, 2017). However, an optimal degree of disaster mitigation would involve expenditures equal to 3.3% of GDP by 2050 (NCSD, 2015). Still, Cambodia expects that only 40% of its climate change funding will come from international sources (RGC, 2017).

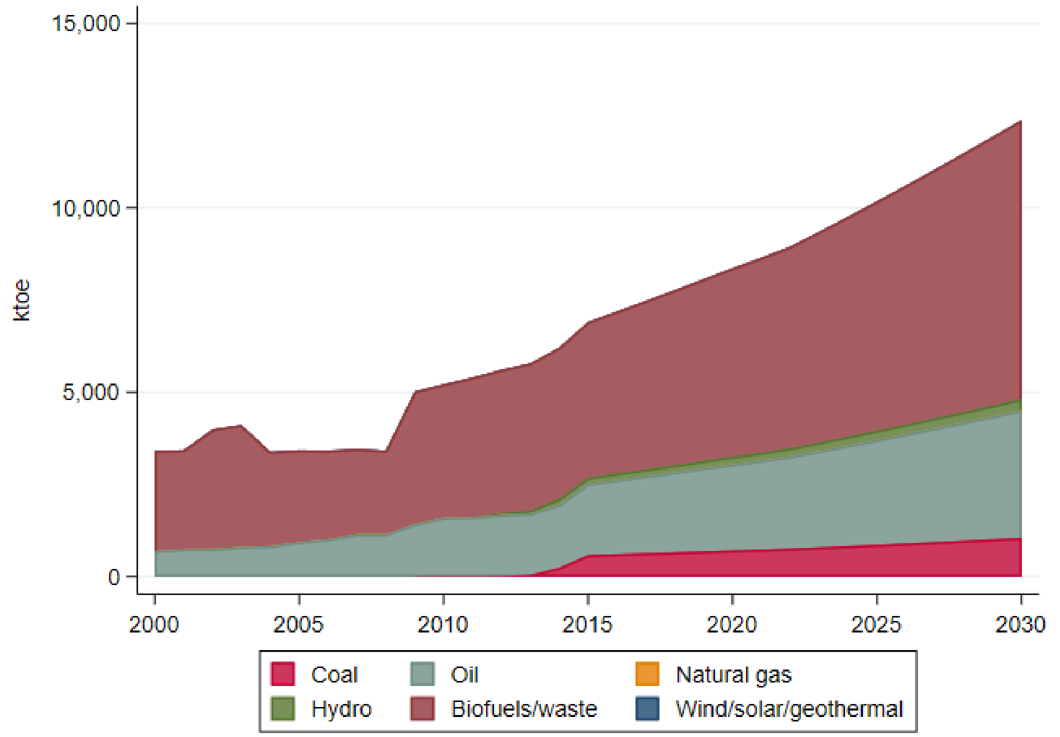

Figure 5.2.2. Cambodia Total Primary Energy Supply (TPES)

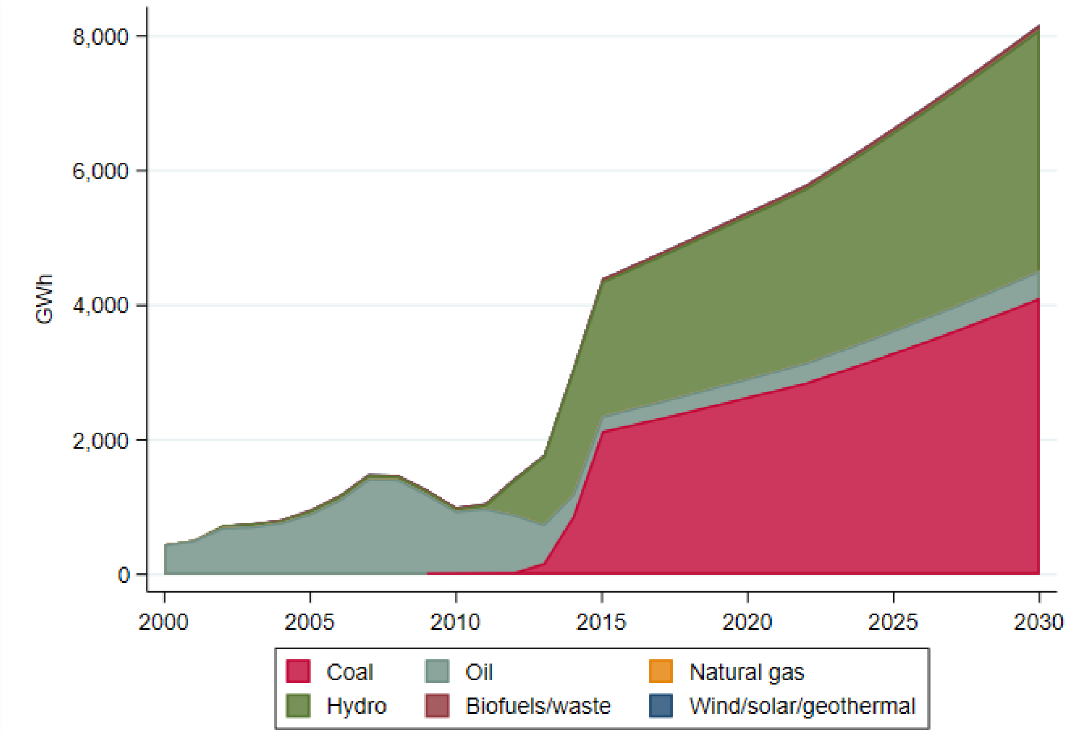

Figure 5.2.3. Cambodia electricity generation

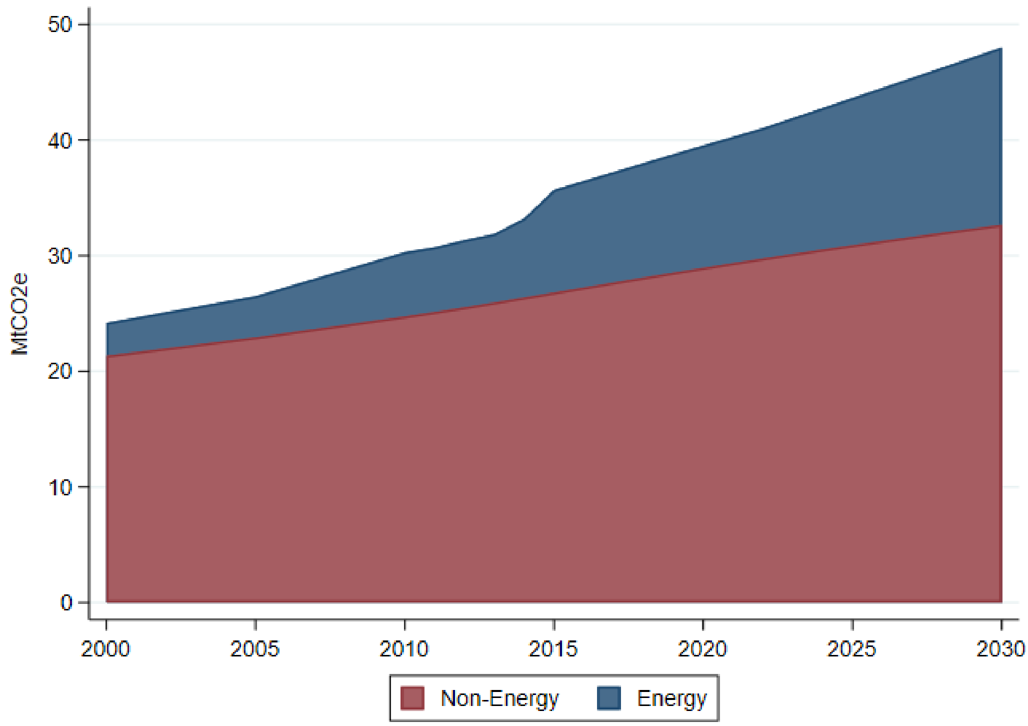

Figure 5.2.4. Cambodia sectoral emissions

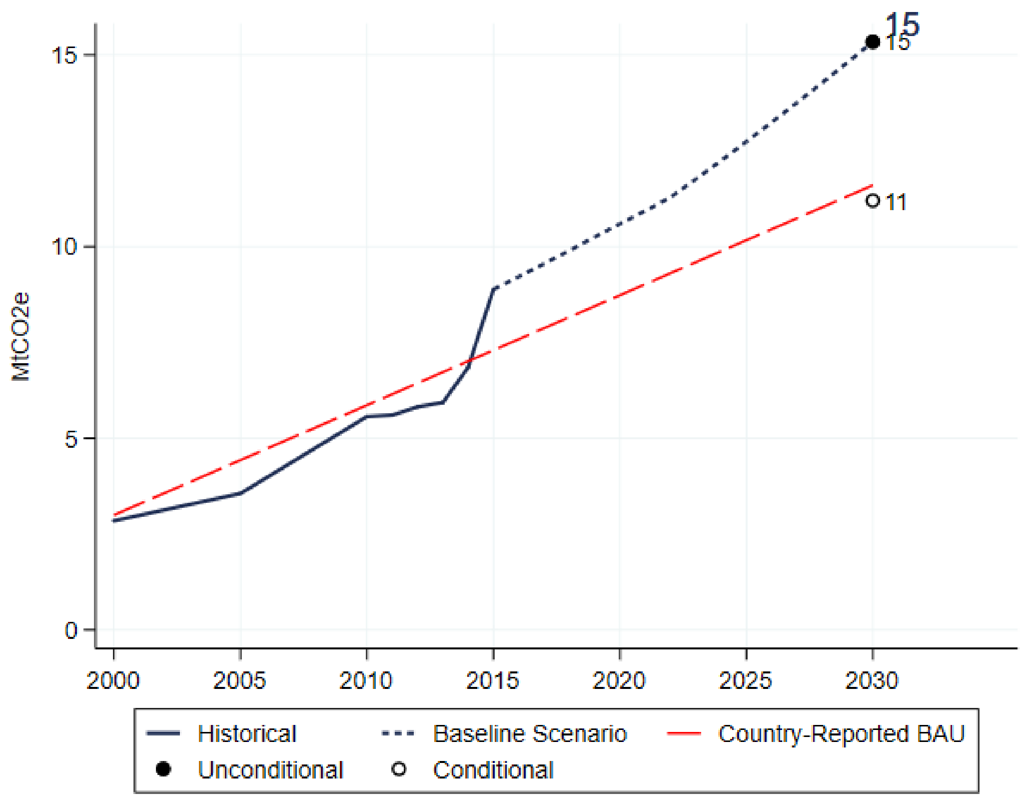

Figure 5.2.5. Cambodia total emissions

Table 5.2.1. Policies and technologies declared in Cambodia's NDC

Type	NDC Reference
Declared Policies	Green Growth Policy and Roadmap (2009)
	Climate Change Strategic Plan (CCCSP) for 2014–2023
	Climate Change Action Plan for Manufacturing Industry and Energy Sectors for 2014–2018
	Climate Change Action Plan for Transport Sector for 2014–2018
	Climate Change Action Plan for Agriculture, Forestry and Fisheries Sector for 2014–2018
	National Forest Programme for 2010–2029
Declared Technologies	Renewable energy generation
	Off-grid electricity (e.g. solar home systems)
	Hybrid and electric vehicles
	Energy-efficient cookstoves
	Biodigesters and water filters

Table 5.2.2. Fuel shares and generation ratios for Cambodia

	Coal	Oil	Natural gas	Hydro	Geothermal/ solar/wind	Biofuels/ waste
2015: TPES Share	0.08	0.28	--	0.02	0.00	0.61
2015: Ratio - generation to TPES (GWh/ktoe)	3.63	0.12	--	11.63	11.63	0.01

Source: Calculations using IEA (2017a)

Table 5.2.3. Projected growth rates for Cambodia

	Average Annual Growth Rates
GDP (2023–2030)	7.04%
TPES per GDP (2016–2030)	-2.71%
Population (2016–2030)	1.46%

Source: Calculations using IEA (2017a), IMF (2017), and UN (2017)

5.3 Indonesia

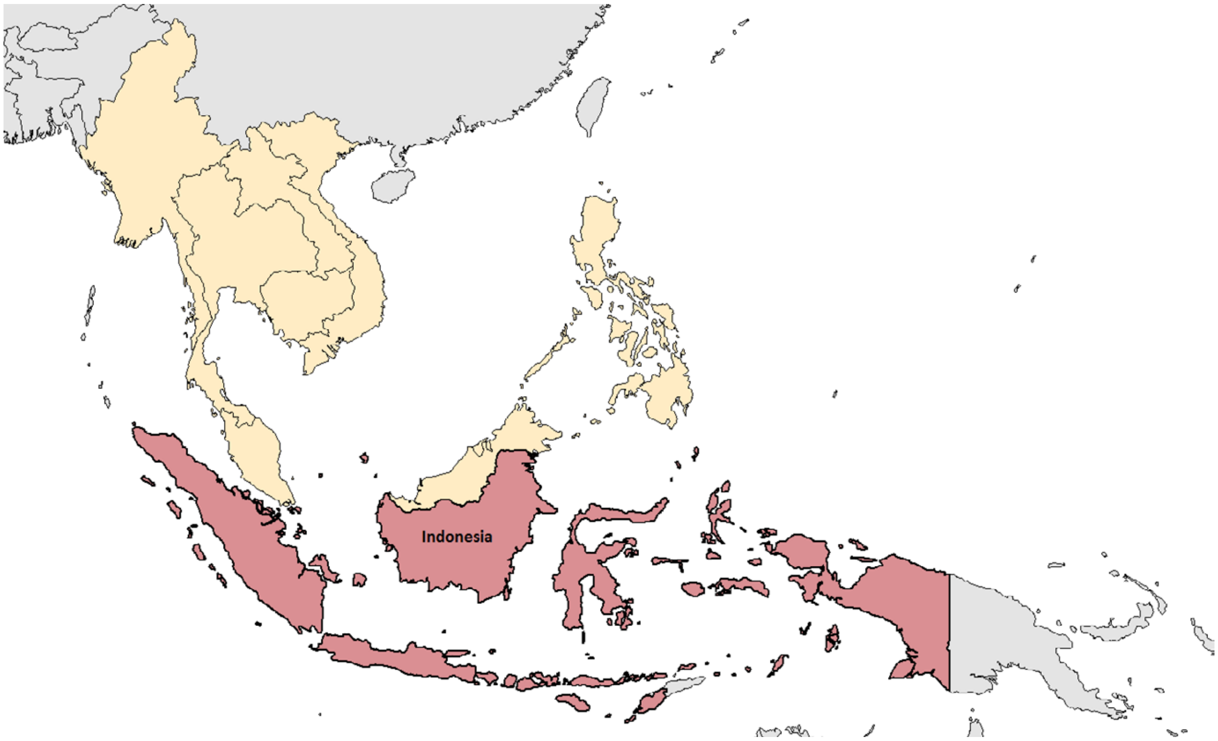

Figure 5.3.1. Map of Indonesia

Indonesia is a diverse nation in Southeast Asia consisting of thousands of islands in the Indian and Pacific Oceans. Indonesia's capital city, Jakarta, is located on the northern coast of the populous island of Java. The country shares a land border with Malaysia on the island Borneo, as well as with Papua New Guinea on the island New Guinea and East Timor on the island Timor.

According to UN (2017), Indonesia had a population of 258 million people in 2015, or 40.8% of the total population in the ASEAN region. Indonesia's population grew an average of 1.34% annually from 2000 to 2015 (compared to the ASEAN rate of 1.27%) and is projected to grow at an average annual rate of 0.91% from 2016 through 2030 (compared to the ASEAN rate of 0.92%).

In 2015 the GDP of Indonesia was 8,983 trillion 2010 Indonesian rupiah (861 billion USD). The country experienced an average annual growth rate of 5.44% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 5.18% average annual growth rate of GDP for 2016 to 2030.

Below we present our projections for energy supply, electricity generation, and GHG emissions in Indonesia. We also describe Indonesia's NDC targets and highlight some of the technologies and policies Indonesia has referenced to meet its commitments. Tables summarizing modeling assumptions for Indonesia are included at the end of this section.

Data on TPES and generation in Indonesia for years 2000 to 2015 is sourced from IEA (2017a). We project that TPES in 2030 will total 427,219 ktoe with 28% from coal, 23% from oil, 27% from natural gas, 19% from biofuels and waste, 2% from non-hydro renewables, and 1% from hydropower. Electricity generation is projected to reach 728,375 GWh in 2030 with a generation mix of 52% coal, 25% natural gas, 2% oil, 7% hydro, and 13% geothermal, solar, and wind. These energy and generation projections mirror the fuel mix targets specified in Indonesia's NDC, as well as the stated goal of 100% electrification (electricity access) by 2020, up from 85% in 2015.

Data for GDP in Indonesia (in 2010 Indonesian rupiah) is taken from IMF (2017). Based on historical trends from 2000 to 2015, we project that energy intensity of GDP in Indonesia will show an average annual decline of 2.8% and reach 0.016 ktoe per billion 2010 rupiah by 2030. See Appendix C for figures illustrating energy intensity of GDP as well as emission intensity of TPES over time.

In the Baseline scenario, Indonesia is projected to emit 1,450 $MtCO_2e$ excluding LULUCF emissions in the year 2030, with emissions from fossil fuel combustion contributing 74.7% of total GHG emissions. In its NDC, Indonesia pledges to reduce total GHG emissions by 29% in 2030 relative to its BAU and by 41% conditional on international financial support. Excluding the LULUCF emission reductions specified in Indonesia's NDC, these pledges correspond to emission reductions of 16% unconditionally and 20% conditionally in 2030 relative to the Baseline scenario, which yield GHG emission targets of 1,218 $MtCO_2e$ and 1,160 $MtCO_2e$, respectively.

In comparison, Indonesia reports a BAU emissions level in 2030 of 2,155 $MtCO_2e$ excluding forestry, with a policy emission target of 1,817 $MtCO_2e$, or 1,723 $MtCO_2e$ conditional on international financial support. For these targets, emission reductions from the energy sector contribute to 93.1% of the emissions gap unconditionally and 92.3% conditionally, according to sectoral targets reported in Indonesia's NDC.

Our calculated Baseline emissions for 2030 fall short of Indonesia's reported BAU (excluding LULUCF emissions) by 705 $MtCO_2e$. These differences largely stem from the energy and waste sectors with Indonesia reporting about 1.5 times the emissions from energy and more than twice the emissions from waste in the 2030 BAU than MIT projects in the Baseline scenario. The discrepancy in energy emissions could in part stem from differences in modeling assumptions—for example, while MIT assumes 20% renewable energy in generation in 2030 in the Baseline scenario, the analysis for Indonesia's NDC assigns this generation to coal-fired power plants rather than renewable sources in the BAU, as noted in the NDC annex.

Indonesia identifies several approaches to achieve its emissions goals. For its unconditional targets, the country plans to product 7.4 GW of renewable generation capacity per the Electricity Supply Business Plan (RUPTL) for 2016–2025. Additional infrastructure for gas distribution lines and compressed natural gas fuel stations will be installed, and biofuel mandates will be put in place for the transportation sector. In the waste sector, landfill gas recovery technologies could reduce methane emissions by up to 10%. For the petrochemical and steel industries, targets for efficiency improvements and emissions reductions from higher feedstock utilization and CO_2 recovery technologies are being developed by the Ministry of Industry.

Additionally, the federal government requires local governments to develop provincial climate action plans. Both the national and local plans are supported through various climate financing mechanisms. Since its inception in 2009, the Indonesia Climate Change Trust Fund (ICCTF) has directed 21.1 million USD from international climate funds to 63 projects across the country, including large initiatives in industrial energy conservation, the sustainable management of biomass, resilience of agricultural methods, and land restoration (ICCTF, 2018; DNPI, 2017). Another funding system, the Joint Crediting Mechanism (JCM), is bilaterally operated by Indonesia and Japan to facilitate the diffusion of Japanese technologies and services to Indonesian projects in support of both countries' emission reduction targets (JCM, 2018).

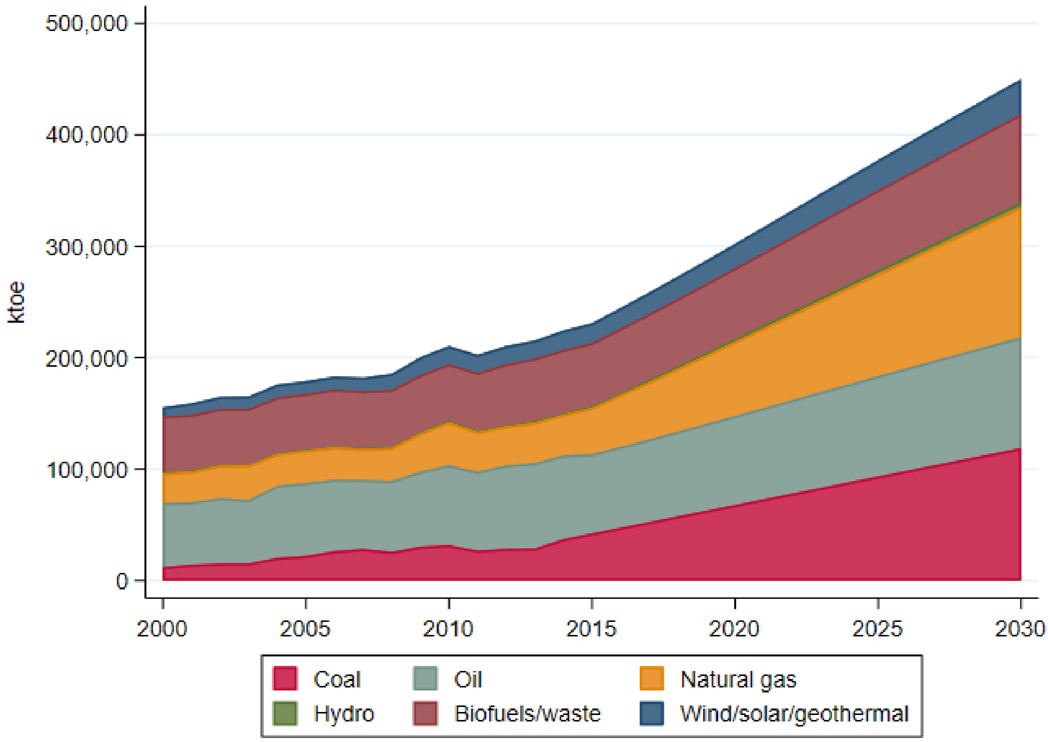

Figure 5.3.2. Indonesia Total Primary Energy Supply (TPES)

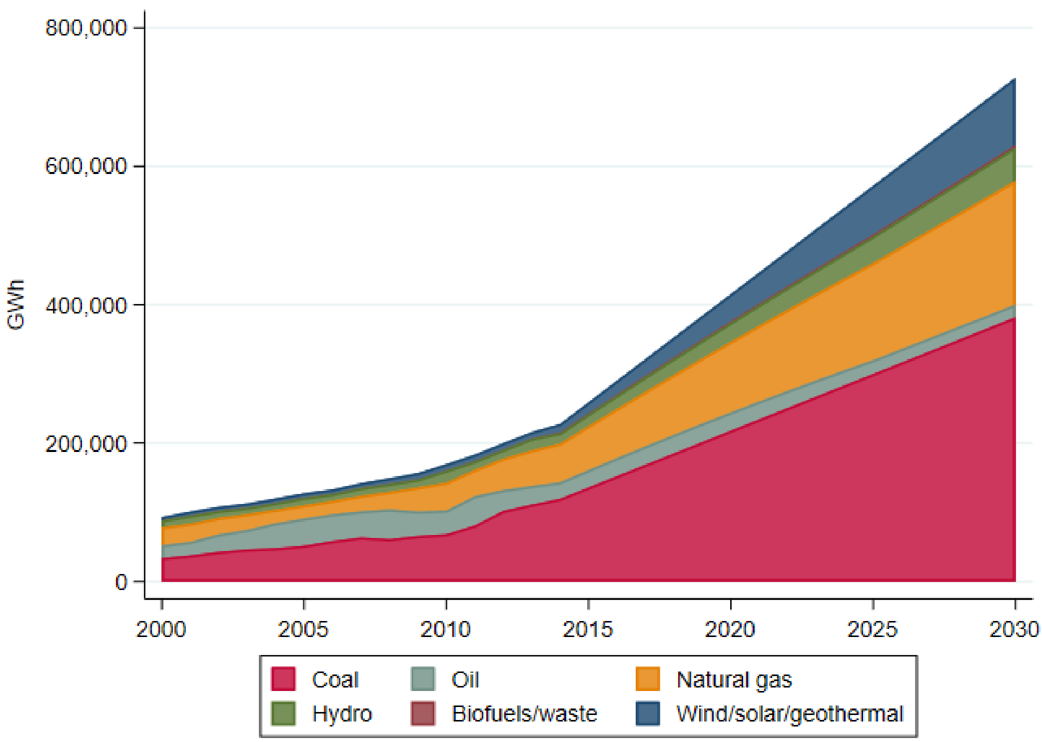

Figure 5.3.3. Indonesia electricity generation

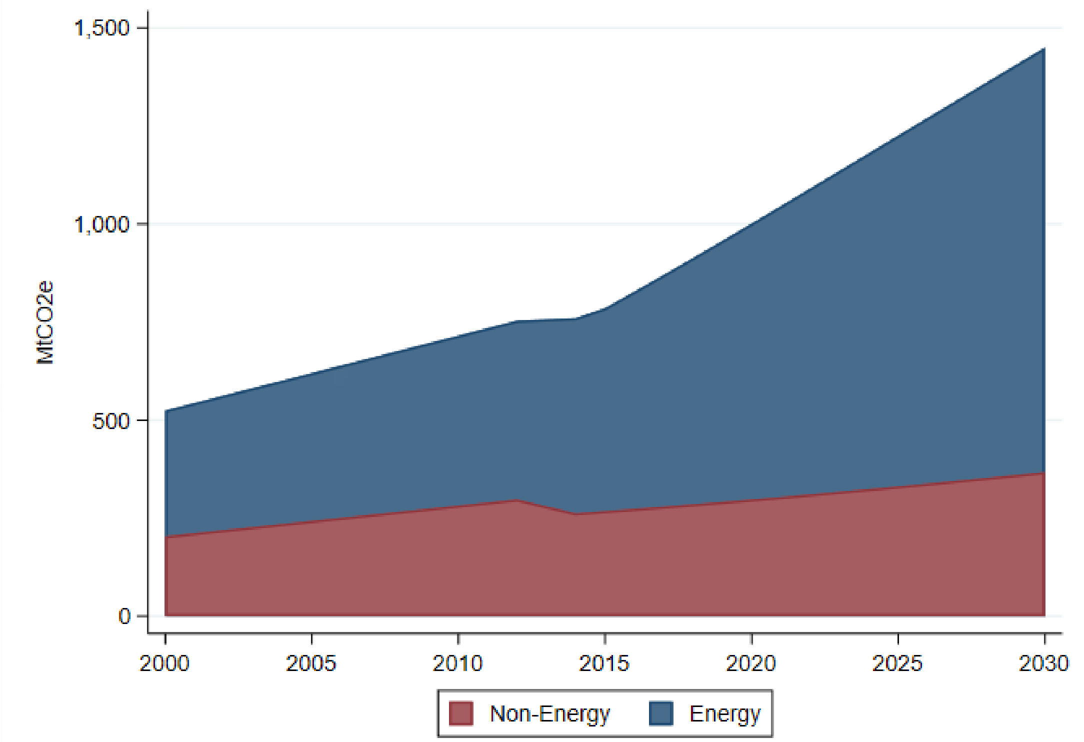

Figure 5.3.4. Indonesia sectoral emissions

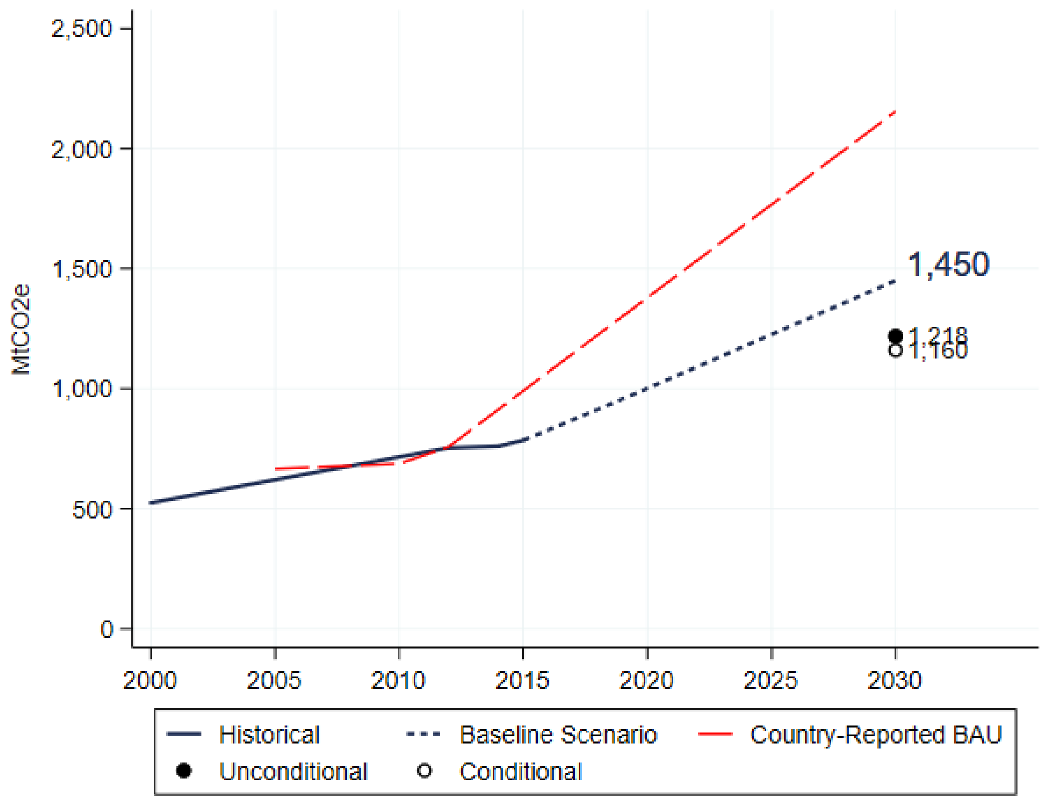

Figure 5.3.5. Indonesia total emissions

Table 5.3.1. Policies and technologies declared in Indonesia's NDC

Type	NDC Reference
Declared Policies	Act No. 18 regarding Solid Waste Management (2008)
	Government Regulation No. 81 regarding Management of Domestic Solid Waste (2012)
	National Energy Policy (KEN) (2014)
	National Energy Plan (RUEN) (2016)
	Electricity Supply Business Plan (RUPTL) for 2016–2025
	National Forestry Plan (RKTN) for 2011–2030
Declared Technologies	Renewable energy generation
	Coal (coal power generation, clean coal technology)
	Natural gas (gas distribution lines, additional compressed-natural gas fuel station)
	Waste management (landfill gas/waste water methane capture/utilization, aerobic septic tank, sludge management, palm oil mill effluent treatment)
	Industry (Improved CO_2 recovery and efficiency in Primary Reformer in petrochemical industry, in aluminum smelter, and in steel industry)
	Biofuels for transport

Table 5.3.2. Fuel shares and generation ratios for Indonesia

	Coal	Oil	Natural gas	Hydro	Geothermal/ solar/wind	Biofuels/ waste
2015: TPES Share	0.20	0.33	0.19	0.01	0.01	0.26
2025: TPES Share	0.26	0.25	0.26	0.01	0.02	0.20
2015: Ratio - generation to TPES (GWh/ktoe)	3.18	0.28	1.56	11.63	0.58	0.02

Source: Calculations using IEA (2017a) and Indonesia's NDC

Table 5.3.3. Projected growth rates for Indonesia

	Average Annual Growth Rates
GDP (2023–2030)	5.05%
TPES per GDP (2016–2030)	-2.79%
Population (2016–2030)	1.12%

Source: Calculations using IEA (2017a), IMF (2017), and UN (2017)

5.4 Lao PDR

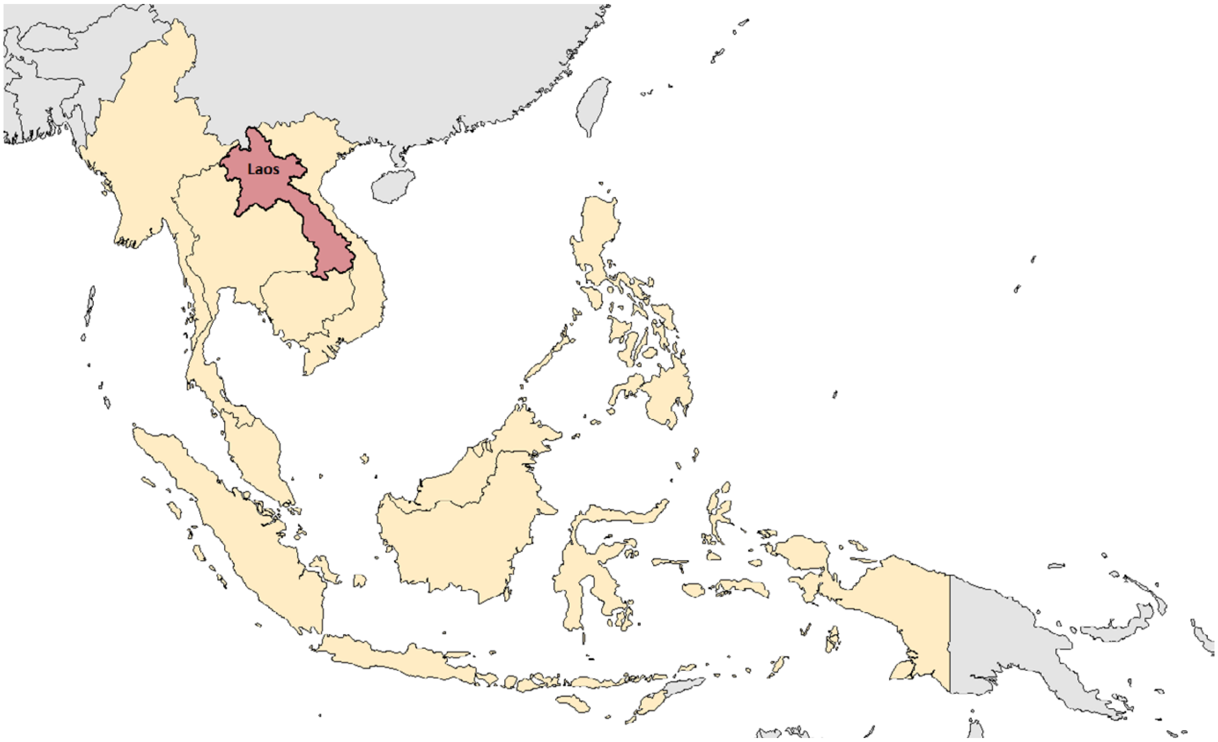

Figure 5.4.1. Map of Lao PDR

Lao PDR is the only landlocked nation in Southeast Asia. Located on the Indochina Peninsula, Lao PDR is bordered by Thailand to the west, Cambodia to the south, Vietnam to the east and northeast, and Myanmar and China to the northwest. The Mekong River defines a large part of the country's western border and runs alongside the Lao capital city Vientiane.

According to UN (2017), Lao PDR had a population of 6.66 million people in 2015, or 1.05% of the total population in the ASEAN region. Lao's population grew an average of 1.50% annually from 2000 to 2015 (compared to the ASEAN rate of 1.27%) and is projected to grow at an average annual rate of 1.27% from 2016 through 2030 (compared to the ASEAN rate of 0.92%).

In 2015 the GDP of Lao PDR was 46 trillion 2002 Lao kip (14.4 billion USD). The country experienced an average annual growth rate of 7.38% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 6.87% average annual growth rate of GDP for 2016 to 2030.

Below we present our projections for energy supply, electricity generation, and GHG emissions in Lao PDR. We also describe Lao's NDC targets and highlight some of the technologies and policies Lao PDR has referenced to meet its commitments. Tables summarizing modeling assumptions for Lao PDR are included at the end of this section.

Data on TPES and generation in Lao PDR for years 2005 to 2014 is sourced from ACE (2017). We project that TPES in 2030 will total 10,357 ktoe with 37% from biofuels and waste, 33% from hydro, 20% from oil, and 10% from coal. Electricity generation is projected to reach 41,566 GWh in 2030 with a generation mix of 99% hydro and 1% biofuels and waste. Our assessment is driven by an abundance of hydro resources in Lao PDR, and currently the government plans to continue with the development of this resource.

Data for GDP in Lao PDR (in 2002 Lao kip) is taken from IMF (2017). Based on historical trends from 2005 to 2014, we project that energy intensity of GDP in Lao PDR will show an average annual decline of 0.8% and reach 0.083 ktoe per billion 2002 kip by 2030. See Appendix C for figures illustrating energy intensity of GDP as well as emission intensity of TPES over time.

In the Baseline scenario, Lao PDR is projected to emit 22.5 $MtCO_2e$ in the year 2030. Lao PDR's Paris Agreement commitments include renewable energy goals, such as large scale hydro generation, and an increase in rural electrification rates among others. For this analysis, we selected to model a 10% reduction in TPES from fossil fuels in 2030 relative to the Baseline scenario, a variation on Lao PDR's targeted 10% reduction in total final energy consumption (TFEC) specified in the 5^{th} ASEAN Energy Outlook (ACE, 2017). The modeled policy yields a conditional GHG emission target of 21.4 $MtCO_2e$ in 2030. No unconditional target is specified, so we assume Baseline emissions in the absence of technical and financial support.

To reduce its emissions, the Lao PDR government has focused on developing a renewable energy strategy which includes increasing the share of consumption from small-scale renewable energy (less than 15 MW capacity) to 30% and the share of biofuels in transport fuels to 10% by 2025, as outlined in its 2011 Renewable Energy Strategy. Additionally, the goal to electrify 90% of rural households by the year 2020 could further reduce emissions by offsetting the combustion of fossil fuels in areas currently without grid access. This renewable energy strategy also contributes to the country's long-term national development goals set out in its 8^{th} Five-Year National Socioeconomic Plan (2016–2020), as Lao PDR aims to transition from a least developed country to a middle-income country by 2030.

Lao PDR also has plans for the installation of 25,500 additional MW of large-scale hydropower plants, which could mitigate 16.3 $MtCO_2e$ per year after 2020, according to Lao PDR government estimates. However, currently almost all of the country's generation comes from renewable sources, and 85% of generated hydropower is exported to Thailand and Vietnam, so Lao PDR's emission reduction calculations likely reflect shifts in energy consumption in its neighboring countries. To implement its objectives for small-scale renewables, large-scale renewables, and rural objectives, Lao PDR estimates a cost of 1.1 billion USD (659 million, 320 million, and 160 million, respectively) for development and ongoing operations. For all mitigation and adaptation measures, Lao PDR has allocated 12.5 million USD, or 0.14% of its GDP in 2012.

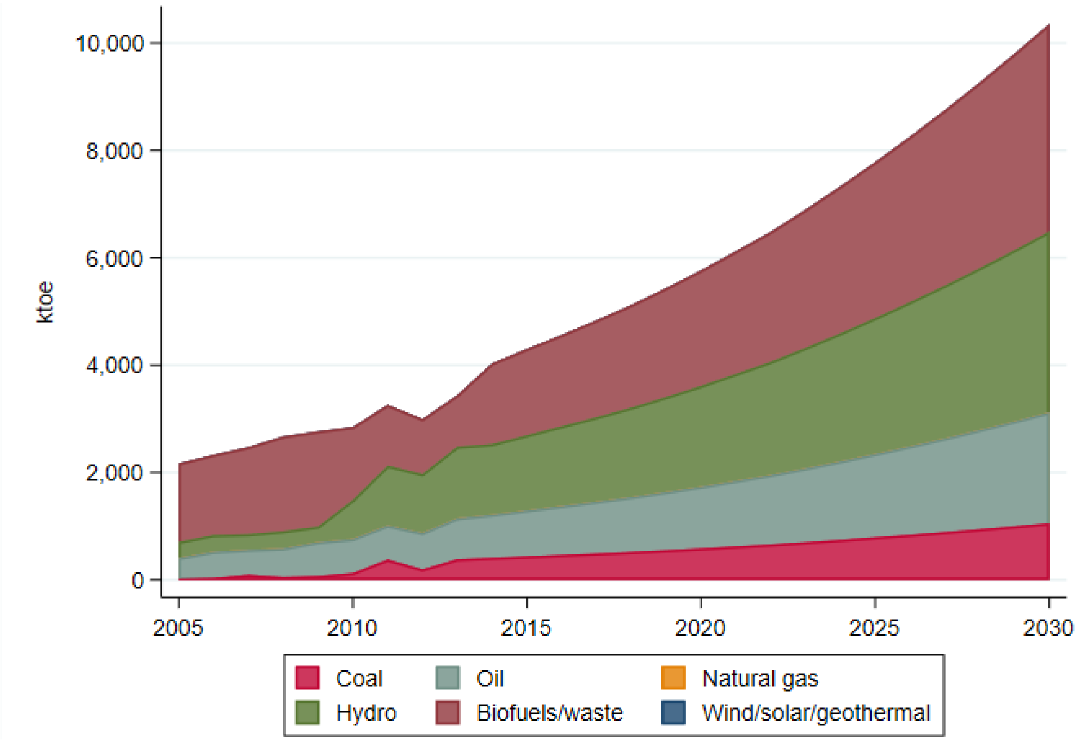

Figure 5.4.2. Lao PDR Total Primary Energy Supply (TPES)

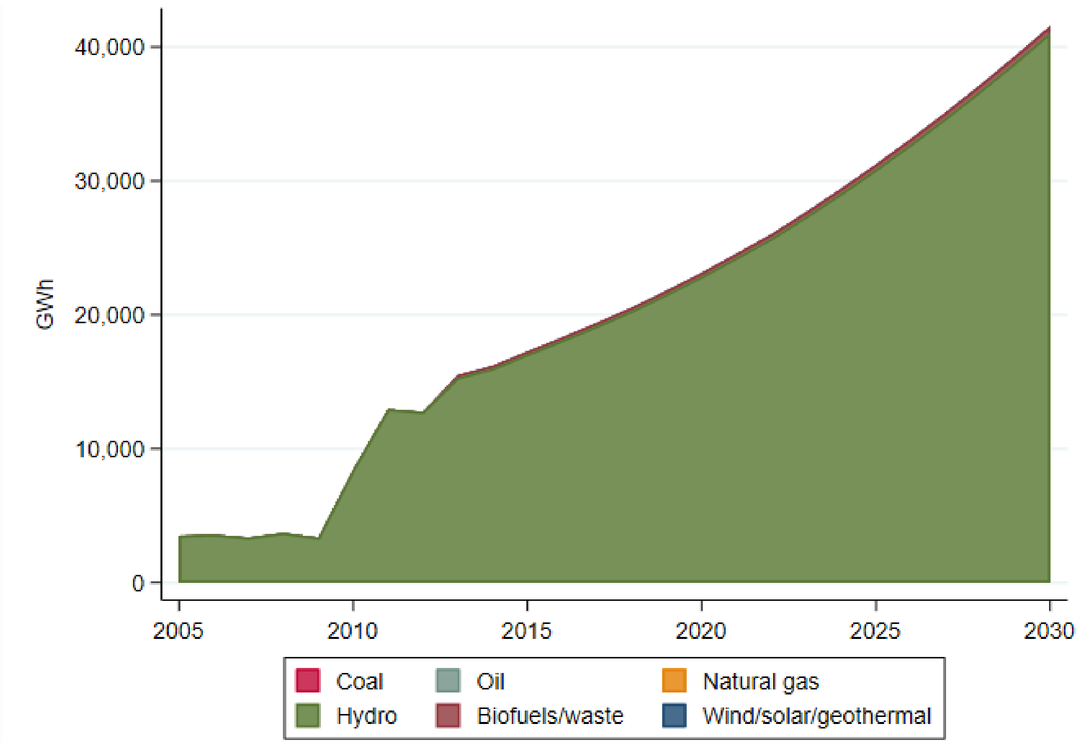

Figure 5.4.3. Lao PDR electricity generation

Table 5.4.1. Policies and technologies declared in Lao PDR's NDC

Type	NDC Reference
Declared Policies	National Strategy on Climate Change (NSCC) (2010)
	Sustainable Transport Development Strategy (2010)
	Renewable Energy Development Strategy (2011)
	Climate Change Action Plan (2013) for 2013–2020
	Climate Change and Disaster Law (exp. 2017)
	National Forest Strategy to the Year 2020
	Rural Electrification Programme
Declared Technologies	Small scale renewable energy production
	Large scale hydroelectricity production
	Biofuels for transport
	Rural electrification
	Road network development
	Public transport

Table 5.4.2. Fuel shares and generation ratios for Lao PDR

	Coal	Oil	Natural gas	Hydro	Geothermal/ solar/wind	Biofuels/ waste
2015: TPES Share	0.10	0.20	--	0.33	--	0.37
2015: Ratio - generation to TPES (GWh/ktoe)	--	--	--	12.19	--	0.13
Source: Calculations using ACE (2017)						

Table 5.4.3. Projected growth rates for Lao PDR

	Average Annual Growth Rates
GDP (2023–2030)	6.87%
TPES per GDP (2016–2030)	-0.78%
Population (2016–2030)	1.38%

Source: Calculations using ACE (2017), IMF (2017), and UN (2017)

5.5 Malaysia

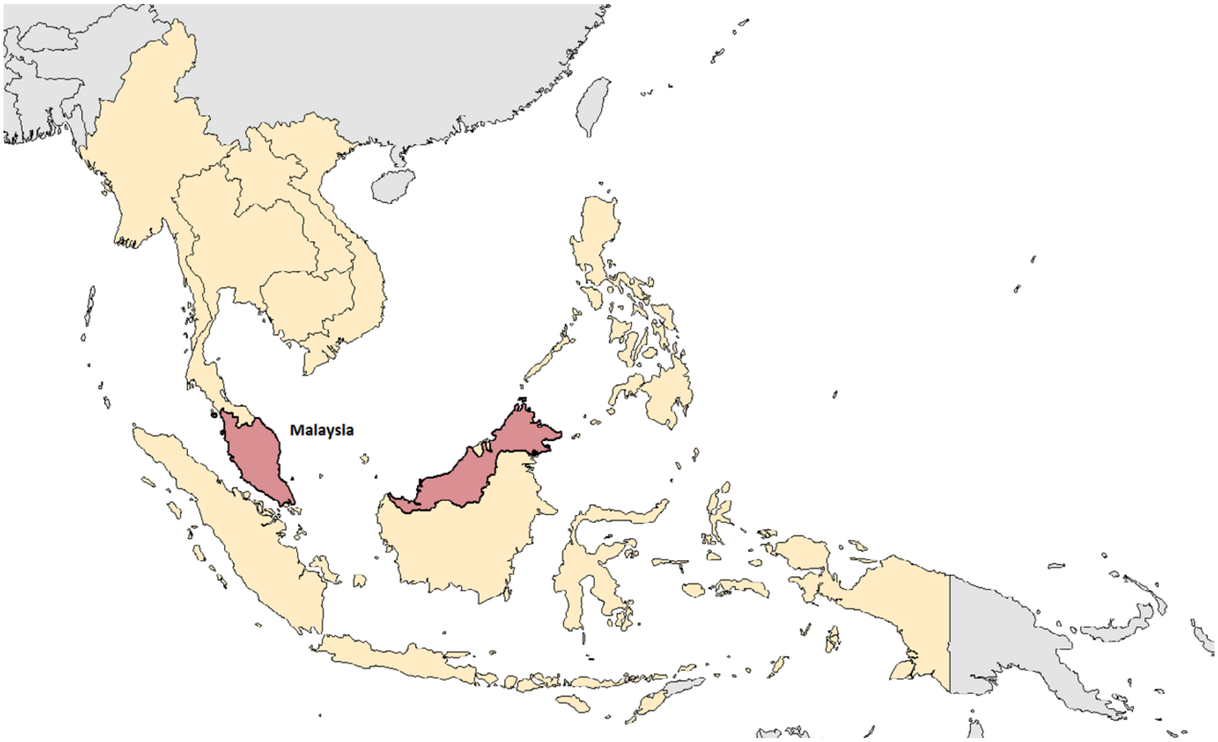

Figure 5.5.1. Map of Malaysia

Malaysia is Southeast Asian country located on the Malay Peninsula and the island of Borneo. Peninsular Malaysia, host to the Malay capital city Kuala Lumpur, borders Thailand to the north and Singapore across the Johor Strait to the south. On the island Borneo—which the country shares with Indonesia and Brunei Darussalam—Malaysia has coastlines along the South China, Sulu, and Celebes Seas.

According to UN (2017), Malaysia had a population of 30.7 million people in 2015, or 4.85% of the total population in the ASEAN region. Malaysia's population grew an average of 1.89% annually from 2000 to 2015 (compared to the ASEAN rate of 1.27%) and is projected to grow at an average annual rate of 1.21% from 2016 through 2030 (compared to the ASEAN rate of 0.92%).

In 2015 the GDP of Malaysia was 1.06 trillion 2010 Malaysian ringgit (296 billion USD). The country experienced an average annual growth rate of 4.82% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 4.55% average annual growth rate of GDP for 2016 to 2030.

Below we present our projections for energy supply, electricity generation, and GHG emissions in Malaysia. We also describe Malaysia's NDC targets and highlight some of the technologies and policies Malaysia has referenced to meet its commitments. Tables summarizing modeling assumptions for Malaysia are included at the end of this section.

Data on TPES and generation in Malaysia for years 2000 to 2015 is sourced from IEA (2017a). We project that TPES in 2030 will total 145,081 ktoe with 44% from natural gas, 32% from oil, 20% from coal, 2% from biofuels and waste, and 1% from hydro and other renewables. Electricity generation is projected to reach 271,194 GWh in 2030 with a generation mix of 43% coal, 47% natural gas, 9% hydro, 1% oil, and 1% biofuels and other non-hydro renewables.

Data for GDP in Malaysia (in 2010 Malaysian ringgit) is taken from IMF (2017). Based on historical trends from 2000 to 2015, we project that energy intensity of GDP in Malaysia will show an average annual decline of 0.95% and reach 70.1 ktoe per billion 2010 ringgit by 2030. See Appendix C for figures illustrating energy intensity of GDP as well as emission intensity of TPES over time.

In the Baseline scenario, Malaysia is projected to emit 544 $MtCO_2e$ excluding LULUCF emissions in the year 2030, with emissions from fossil fuel combustion contributing 80.1% of total GHG emissions. In its NDC, Malaysia pledges to reduce its emissions intensity of GDP by 35% in 2030 relative to 2005 and by 45% conditional on international financial support. These commitments correspond to total GHG emission targets of 540 $MtCO_2e$ unconditionally and 457 $MtCO_2e$ conditionally in 2030.

As suggested by its NDC, Malaysia primarily intends to meet its emission intensity goals (estimated as an unconditional emissions reduction of 88 $MtCO_2e$ in 2030 relative to the Baseline scenario) through renewable energy generation and consumption and financial tools. Malaysia already promotes the use of biofuels in transportation through the National Biofuel Industry Act of 2007, which mandates 5% palm biodiesel in fuel for transport and was recently updated to 7% in 2014. Additionally, the introduction of feed-in-tariff mechanisms and financial incentives for green technology investments encourage renewable energy production. More specifically, the government has invested RM 2.6 billion to support low-carbon technology projects, and has allocated an additional RM 2.3 in its 11th Malaysia Plan. The government also established a Green Technology Financing Scheme for 2010 to 2017 equipped with RM 3.5 billion to further support green technology investments in the industrial sector (Govindaraju, 2017).

Malaysia also identifies key challenges to meeting its energy intensity goals, including the high capital costs of rail transport systems and current limits to electrification of these systems based on fossil fuels' large share in the national energy supply.

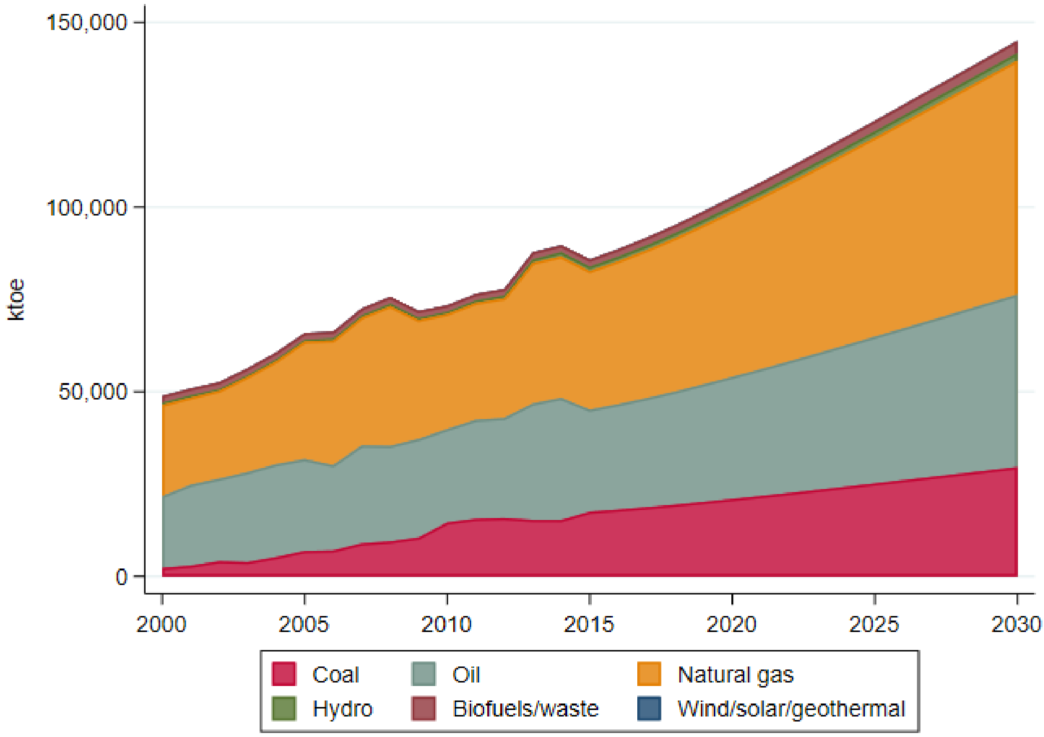

Figure 5.5.2. Malaysia Total Primary Energy Supply (TPES)

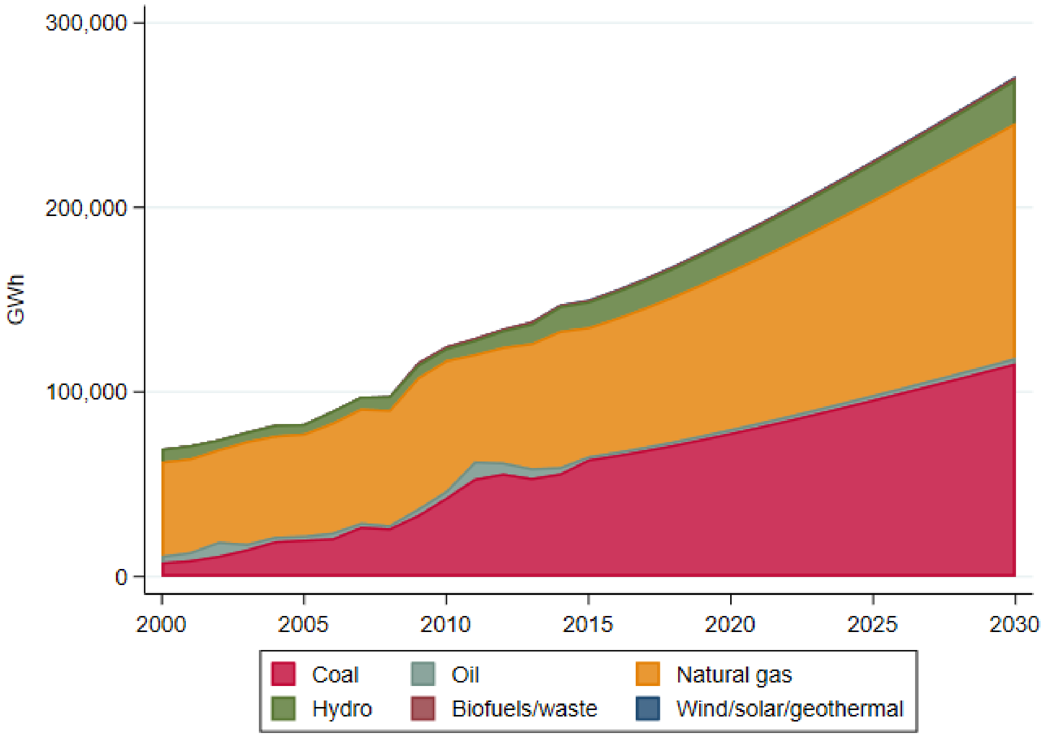

Figure 5.5.3. Malaysia electricity generation

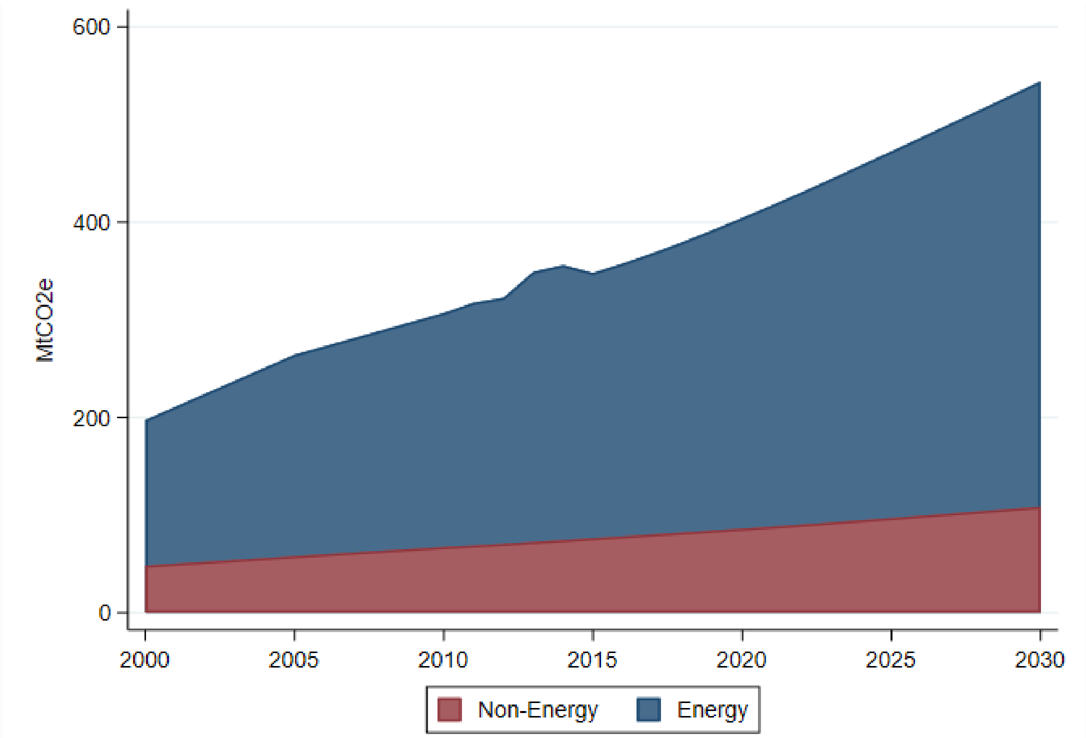

Figure 5.5.4. Malaysia sectoral emissions

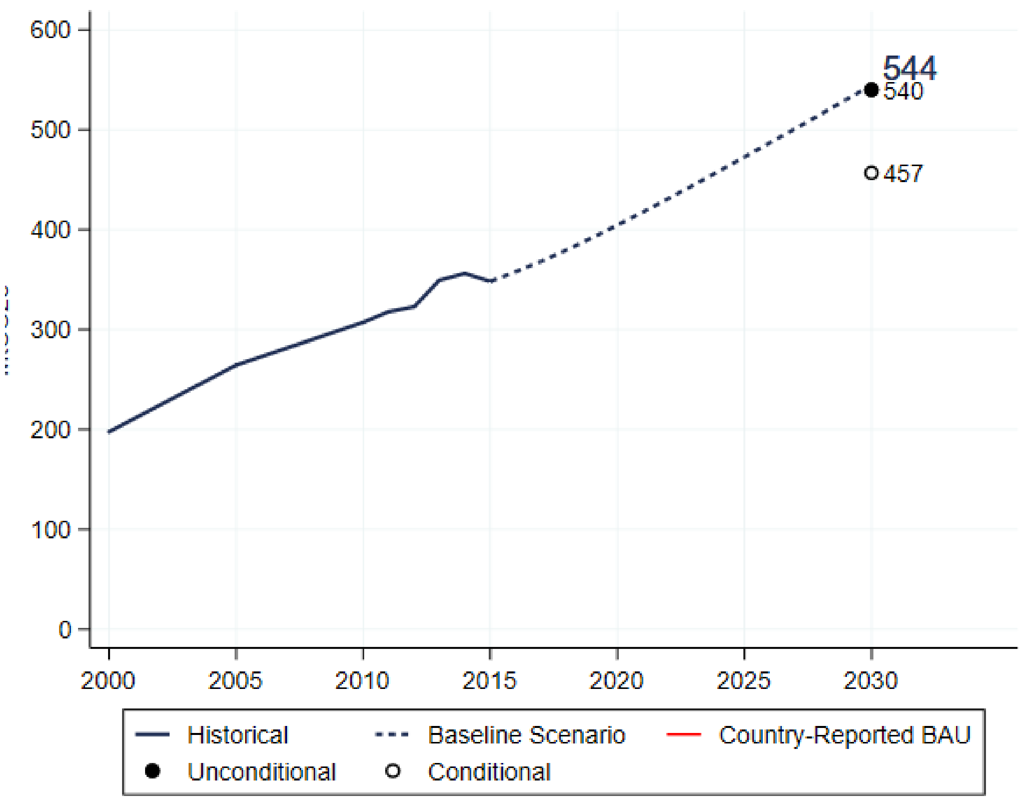

Figure 5.5.5. Malaysia total emissions

Table 5.5.1. Policies and technologies declared in Malaysia's NDC

Type	NDC Reference
Declared Policies	National Petroleum Policy (1975)
	National Energy Policy (1979)
	National Depletion Policy (1980)
	Four-Fuel Diversification Policy (1981)
	National Forestry Policy (1978, rev. 1992)
	National Policy on Biological Diversity (1998)
	Five Fuel Policy (2001)
	National Policy on the Environment (2002)
	National Strategic Plan for Solid Waste Management (2005)
	National Biofuel Policy (2006)
	National Energy Policy (2008)
	National Green Technology Policy (2009)
	New Economic Model, Government Transformation Programme and Economic Transformation Programme (2010)
	Renewable Energy Policy and Action Plan (2010)
	Second National Physical Plan (2010)
	Low Carbon Cities Framework (2011)
	National Agro-food Policy (2011)
	National Water Resources Policy (2012)
	National Automotive Policy (2014)
Declared Technologies	Renewable energy generation
	Biofuels in industry

Table 5.5.2. Fuel shares and generation ratios for Malaysia

	Coal	Oil	Natural gas	Hydro	Geothermal/ solar/wind	Biofuels/ waste
2015: TPES Share	0.20	0.32	0.44	0.01	0.00	0.02
2015: Ratio - generation to TPES (GWh/ktoe)	3.62	0.06	1.86	11.63	11.63	0.39
Source: Calculations using IEA (2017a)						

Table 5.5.3. Projected growth rates for Malaysia

	Average Annual Growth Rates
GDP (2023–2030)	4.43%
TPES per GDP (2016–2030)	-0.95%
Population (2016–2030)	1.55%

Source: Calculations using IEA (2017a), IMF (2017), and UN (2017)

5.6 Myanmar

Figure 5.6.1. Map of Myanmar

Myanmar is a Southeast Asian country located on the Indochina Peninsula, with the country's southernmost tip entering the northern portion of Malay Peninsula. Myanmar has a long western coast on the Bay of Bengal and the Andaman Sea, and borders Thailand to the east and southeast, China to the northeast, and Bangladesh to the northwest. The Burmese capital city Naypyidaw is located in central region of the country. Assigned the 3rd highest rating in the Germanwatch Long-Term Climate Risk Index, Myanmar has been identified as one of the world's countries most affected by extreme weather events over the past 20 years (Eckstein *et al.*, 2017).

According to UN (2017), Myanmar had a population of 52.4 million people in 2015, or 8.27% of the total population in the ASEAN region. Myanmar's population grew an average of 0.86% annually from 2000 to 2015 (lower than the ASEAN rate of 1.27%) and is projected to grow at an average annual rate of 0.78% from 2016 through 2030 (compared to the ASEAN rate of 0.92%).

In 2015 the GDP of Myanmar was 56.6 trillion 2010/11 Myanmar kyat (59.5 billion current USD). The country experienced an average annual growth rate of 9.29% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 7.87% average annual growth rate of GDP for 2016 to 2030.

Below we present our projections for energy supply, electricity generation, and GHG emissions in Myanmar. We also describe Myanmar's NDC targets and highlight some of the technologies and policies Myanmar has referenced to meet its commitments. Tables summarizing modeling assumptions for Myanmar are included at the end of this section.

Data on TPES and generation in Myanmar for years 2000 to 2015 is sourced from IEA (2017a). We project that TPES in 2030 will total 25,177 ktoe with 51% from biofuels and waste, 27% from oil, 15% from natural gas, 4% from hydro, and 2% from coal. Electricity generation is projected to reach 20,919 GWh in 2030 with a generation mix of 57% hydro, 41% natural gas, less than 2% coal, and less than 1% oil. For Myanmar we use a conservative view that the 2010–

2015 changes were driven by a temporary re-structuring. Myanmar has one of the lowest electricity per capita consumption in the ASEAN (see Figures 3.7–3.8) and the realized growth will be dramatically affected by the government policies and political developments. With more stable conditions, the growth in energy and electricity might be substantially higher.

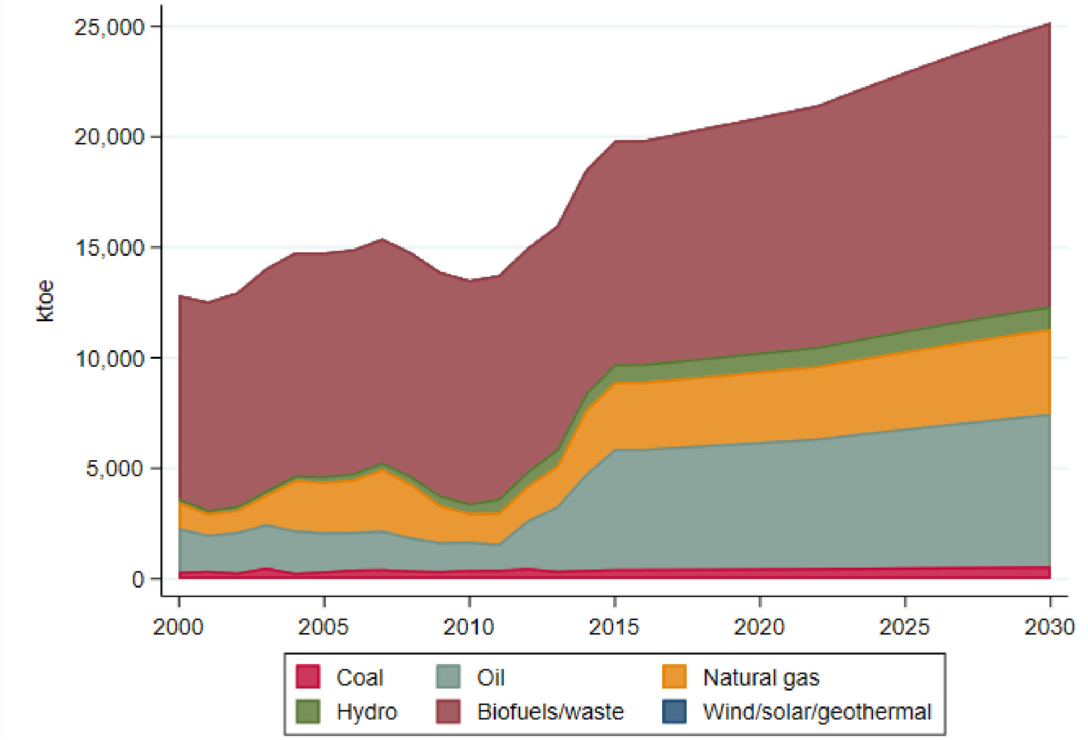

Figure 5.6.2. Myanmar Total Primary Energy Supply (TPES)

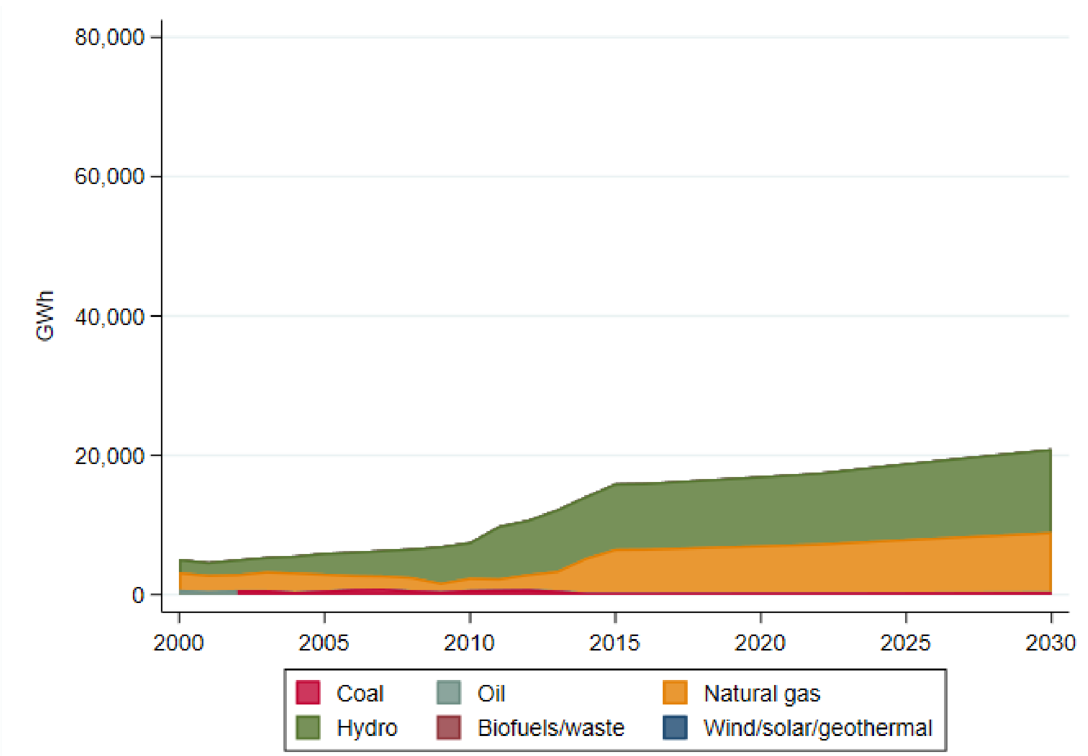

Figure 5.6.3. Myanmar electricity generation

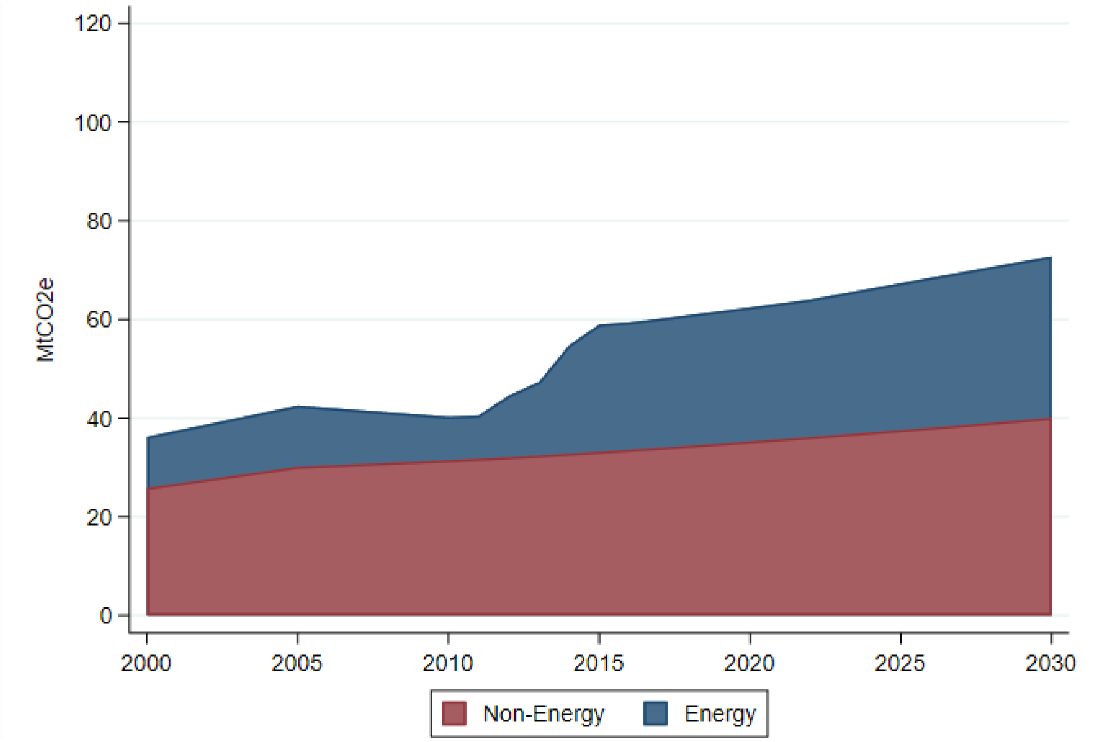

Figure 5.6.4. Myanmar sectoral emissions

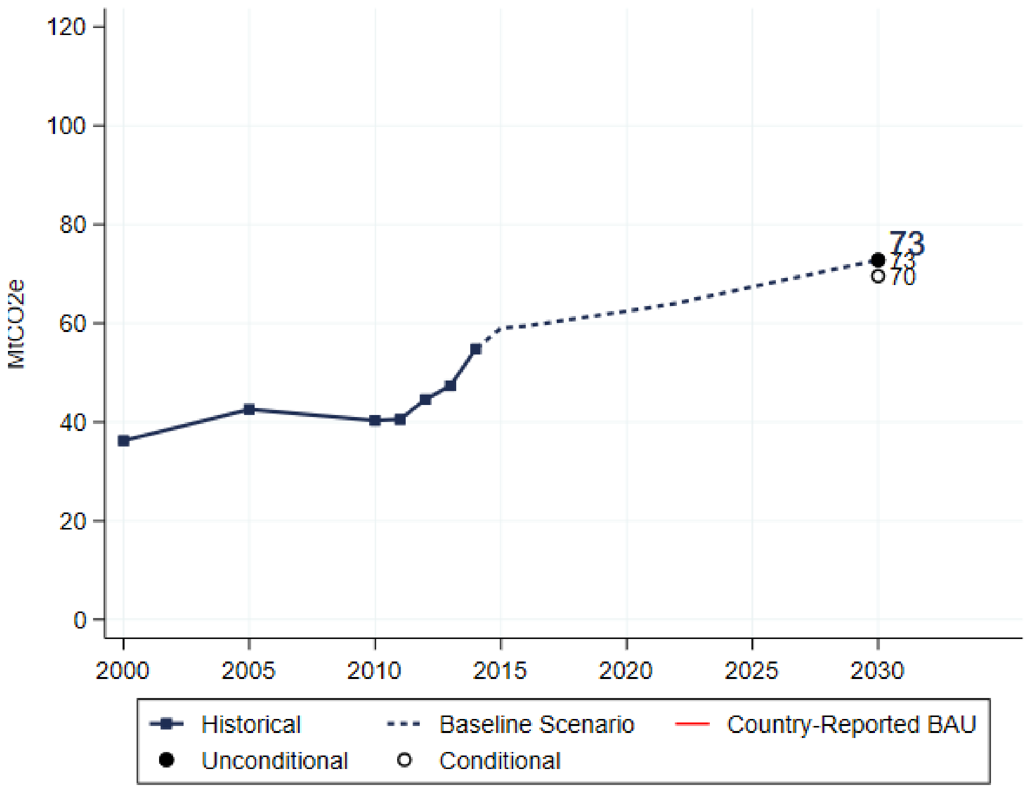

Figure 5.6.5. Myanmar total emissions

Data for GDP in Myanmar (in 2010/11 Myanmar kyat) is taken from IMF (2017). Based on historical trends from 2000 to 2015, we project that energy intensity of GDP in Myanmar will show an average annual decline of 5.8% and reach 0.143 ktoe per billion 2010/11 kyat by 2030. See Appendix C for figures illustrating energy intensity of GDP as well as emission intensity of TPES over time.

In the Baseline scenario, Myanmar is projected to emit 72.8 $MtCO_2e$ excluding LULUCF emissions in the year 2030, with emissions from fossil fuel combustion contributing 44.9% of total GHG emissions. Myanmar's Paris Agreement commitments include expanded hydropower generation, increased rates of rural electrification[5], and improved energy efficiency among others. For this analysis, we modeled Myanmar's policy targets as (1) an increase in hydropower capacity to 9.4 GW in 2030 for an estimated hydro output of 16,469 GWh, followed by (2) a 20% reduction in fossil-based generation in 2030, under the assumption that remaining generation in the Baseline scenario would be met by non-hydro sources according to fuel shares in 2015. The 20% reduction in fossil-based generation is derived as a variation of a targeted 20% reduction in electricity consumption specified under Myanmar's ASEAN Member State (AMS) Target Scenario in the 5th ASEAN Energy Outlook (ACE, 2017). The modeled expansion of hydropower and decrease in fossil-based generation yields a conditional GHG emission target of 69.6 $MtCO_2e$ in 2030. No unconditional target is specified, so we assume Baseline emissions in the absence of technical and financial support.

We also consider policy targets applied to an *alternative* reference scenario (Baseline B) constructed from generation capacities specified in Myanmar's AMS Target Scenario. In Baseline B, Myanmar has fuel-specific generation capacities in 2030 of 8,896 MW hydro; 7,940 MW coal, 4,758 MW natural gas, and 2,000 MW non-hydro renewables, which we estimate to yield total generation of 82,021 GWh and economy-wide emissions of 111 $MtCO_2e$, compared to 20,919 GWh and 72.8 $MtCO_2e$ in the original Baseline scenario (Baseline A). Table 5.6.1 summarizes the difference in generation by fuel in the alternative Baseline scenarios while Figure 5.6.6 illustrates the generation mix in Baseline B. As illustrated in Figure 5.6.7, applying a 20% reduction to fossil-based generation in Baseline B yields an emissions target of 101 $MtCO_2e$ in 2030 (compared to 69.6 $MtCO_2e$ in Baseline A), conditional on financial support.

Table 5.6.1. Myanmar's generation in 2030 in alternative Baseline scenarios

Scenario	Generation in 2030 (GWh)					
	Coal	*Oil*	*Natural Gas*	*Hydro*	*Other Renewables*	*Total*
A	390	70	8,526	11,933	0	20,919
B	38,255	0	22,924	15,586	5,256	82,021

Myanmar's primary intended mitigation actions encompass hydroelectric power generation, rural electrification from renewables, and energy efficiency in industrial process. Specifically, Myanmar is drafting its Long Term Energy Master Plan and National Electrification Master Plan to support the installation of additional hydropower capacity (for a total of 9.4 GW in 2030), compared to our estimate of a 2015 hydro capacity of 5.4 GW. Through its National Electrification Plan (NEP), Myanmar also aims to increase electrification for 6 million rural residents using at least 30% renewable energy sources, and to increase the national electrification rate from 33% of all residents in 2014 to 100% in 2030 (World Bank, 2014). Most immediately for off-grid rural villages, Myanmar is exploring solar homes and mini-grids depending on village size. While Myanmar has produced internal estimates of anticipated emission reductions from these actions, it considers the estimates too unreliable to report in their current form but intend to provide reduction estimates in future revisions of its NDC.

In addition to these energy sector goals, Myanmar names several policies and plans under development to implement a greater climate change response. These policies make provisions for sustainability projects, management plans, and impact assessments in the areas of forest

5 Myanmar's national rate of electrification in 2015 was 26%, the lowest of the ASEAN Member States.

management, energy, housing, transportation, and other sectors, and promote technology options including sustainable transportation options and bioengineering measures to reduce soil erosion.

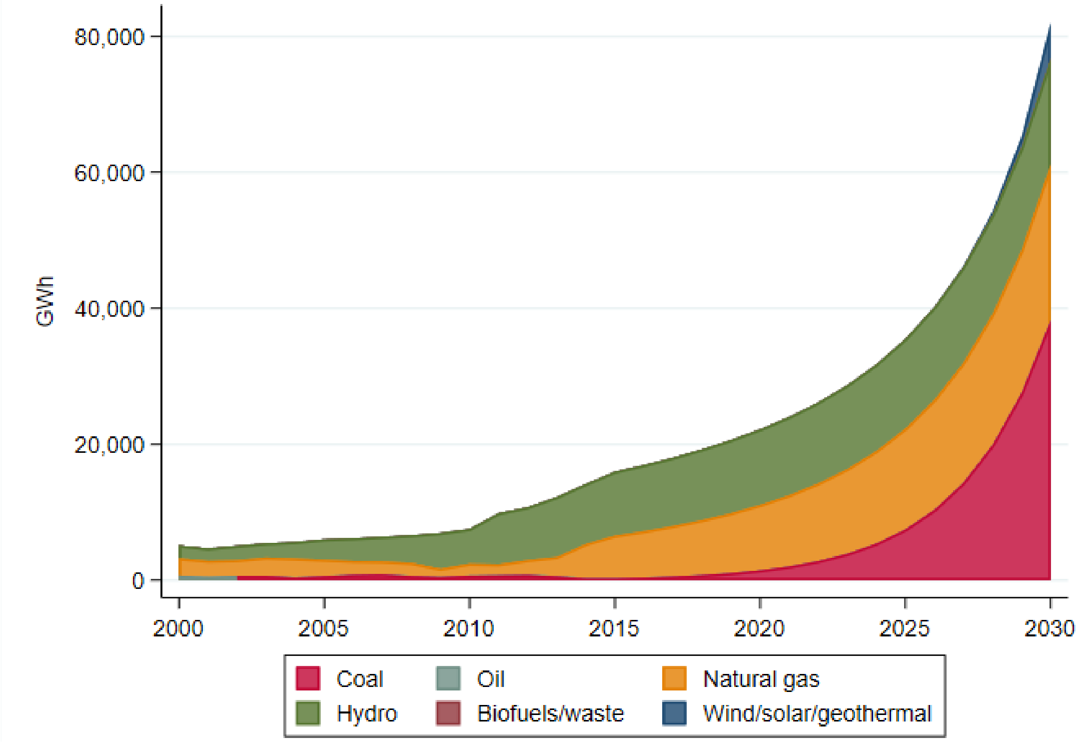

Figure 5.6.6. Myanmar electricity generation in alternative Baseline B

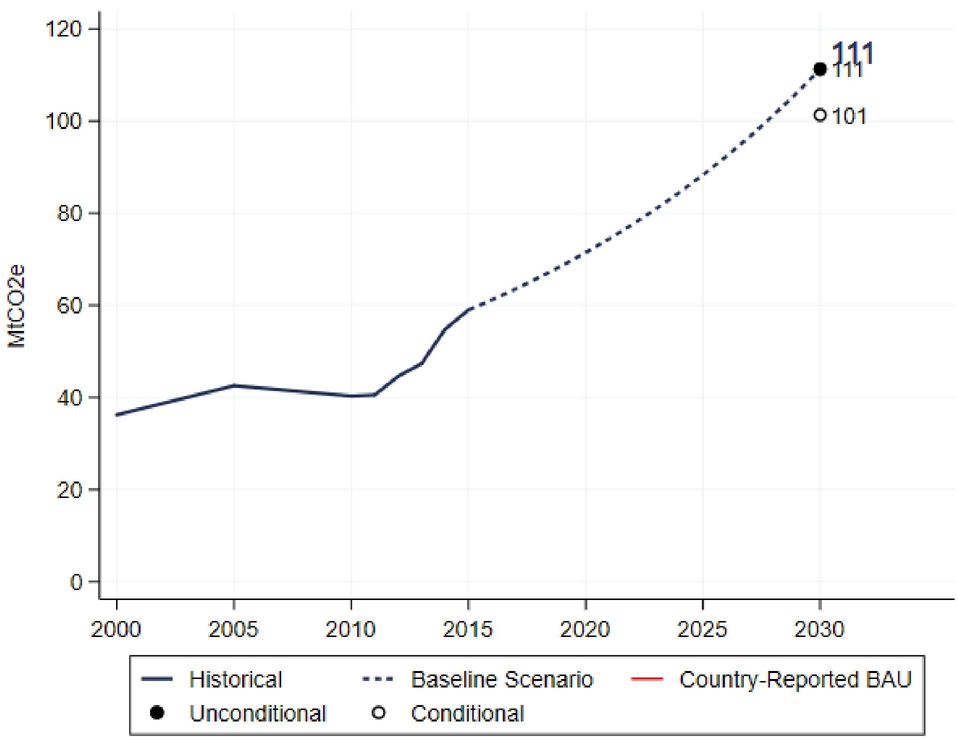

Figure 5.6.7. Myanmar total emissions in alternative Baseline B

Table 5.6.2. Policies and technologies declared in Myanmar's NDC

Type	NDC Reference
Declared Policies	National Biodiversity Strategy and Action Plan (2011)
	Environmental Conservation Law (2012)
	National Energy Policy (2014)
	30-Year National Forest Master Plan for 2001–2030
	Under development:
	Long Term Energy Master Plan (exp. 2016)
	National Electrificity Master Plan
	Rural Electrification Plan (exp. 2017)
	National Climate Change Strategy and Action Plans
	National Climate Change Policy (exp. 2016)
	Green Economy Strategic Framework (exp. 2016)
	Comprehensive Village Development Plan
	National Energy Efficiency and Conservation Policy (exp. 2015)
	Comprehensive Plan for Dry Zone Greening for 2001–2030
	National Environmental Policy (to update 1994 National Environmental Policy)
	National Waste Management Strategy and Action Plans (exp. 2017)
	Urban development plans
Declared Technologies	Hydroelectric generation
	Renewable energy for rural electrification
	Energy management systems in industry
	Energy system optimization
	Energy-efficient cookstoves

Table 5.6.3. Fuel shares and generation ratios for Myanmar

	Coal	Oil	Natural gas	Hydro	Geothermal/ solar/wind	Biofuels/ waste
2015: TPES Share	0.02	0.27	0.15	0.04	--	0.51
2015: Ratio - generation to TPES (GWh/ktoe)	0.64	0.01	2.06	11.63	--	--
Source: Calculations using IEA (2017a)						

Table 5.6.4. Projected growth rates for Myanmar

	Average Annual Growth Rates
GDP (2023–2030)	8.32%
TPES per GDP (2016–2030)	-5.81%
Population (2016–2030)	0.82%

Source: Calculations using IEA (2017a), IMF (2017), and UN (2017)

5.7 The Philippines

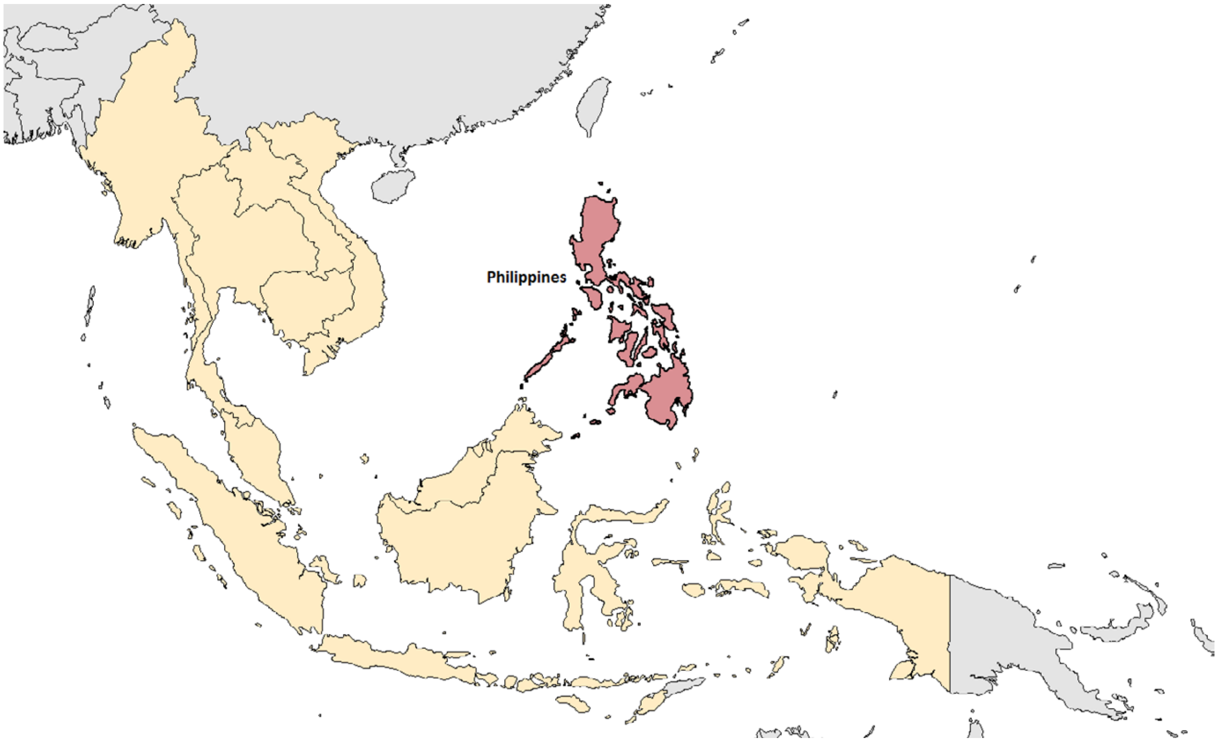

Figure 5.7.1. Map of The Philippines

The Philippines is a Southeast Asian country and archipelago in the Pacific Ocean. It is bordered by the South China Sea to the west, the Celebes Sea to the south, and the Philippines Sea to the east. The Philippines capital city Manila is located on the western coast of Luzon, a large island in the northern part of the archipelago. Assigned the 5th highest rating in the Germanwatch Long-Term Climate Risk Index, the Philippines has been identified as one of the world's countries most affected by extreme weather events over the past 20 years (Eckstein *et al.*, 2017).

According to UN (2017), the Philippines had a population of 101.7 million people in 2015, or 16.1% of the total population in the ASEAN region. The Philippines' population grew an average of 1.79% annually from 2000 to 2015 (compared to the ASEAN rate of 1.27%) and is projected to grow at an average annual rate of 1.40% from 2016 through 2030 (compared to the ASEAN rate of 0.92%).

In 2015 the GDP of The Philippines was 7.59 trillion 2000 Philippine pesos (292.8 billion USD). The country experienced an average annual growth rate of 5.14% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 6.10% average annual growth rate of GDP for 2016 to 2030.

Below we present our projections for energy supply, electricity generation, and GHG emissions in the Philippines. We also describe the Philippines's NDC targets and highlight some of the technologies and policies that the Philippines has referenced to meet its commitments. Tables summarizing modeling assumptions for the Philippines are included at the end of this section.

Data on TPES and generation in the Philippines for years 2000 to 2015 is sourced from IEA (2017a). We project that TPES in 2030 will total 77,890 ktoe with 34% from oil, 24% from coal, 6% from natural gas, 17% from biofuels and waste, and 19% from other renewables. Electricity generation is projected to reach 129,544 GWh in 2030 with a generation mix of 46% coal, 23% natural gas, 14% geothermal/solar/wind, 10% hydro, and 7% oil.

Data for GDP in the Philippines (in 2000 Philippine pesos) is taken from IMF (2017). Based on historical trends from 2000 to 2015, we project that energy intensity of GDP in the Philippines will show an average annual decline of 3.2% and reach 4.22 ktoe per billion 2000 pesos by 2030. See Appendix C for figures illustrating energy intensity of GDP as well as emission intensity of TPES over time.

In the Baseline scenario, the Philippines is projected to emit 293 $MtCO_2e$ excluding LULUCF emissions in the year 2030, with emission from fossil fuel combustion contributing 58.5% of total GHG emissions. In its NDC, the Philippines pledges to reduce total GHG emissions by 70% in 2030 relative to its BAU conditional on international financial support, which yields a conditional GHG emission target of 88 $MtCO_2e$ in 2030. No unconditional target is specified, so we assume Baseline emissions in the absence of technical and financial support.

The Philippines established the Climate Change Commission (CCC) in 2009 to spearhead its emission reduction efforts, with the Philippine government stating that its mitigation actions will be selected according to the country's climate vulnerabilities and adaptation priorities (see the 2010 National Framework Strategy on Climate Change). In its National Climate Change Action Plan for 2011 to 2028, the CCC identifies climate-aware development and community resilience as overarching objectives for national climate policy and lists seven strategic policies—including water sufficiency, "climate-smart" industries, and sustainable energy—and their associated activities, indicators, outcomes, and involved institutions (CCC, 2011). Within the industrial sector, for example, the CCC aims to increase resource-efficiency by enhancing end-of-life management for electronics, vehicles, and other products; identify tools and partners to assist with resource management; and retrofit vulnerable municipal infrastructure among the creation of other initiatives and supporting policies. In the sustainable energy domain, the CCC intends to increase adoption of demand-side management technologies; streamline the approval process for renewable energy projects; electrify 4,000 off-grid households through renewable energy systems; implement a government clean fleet program and incentivize company clean fleet adoption; and "climate-proof" existing energy and transportation infrastructure, among other initiatives.

Looking at energy goals more specifically, the CCC plan targets a 10% energy savings across all sectors between 2011 and 2028, for 4,798 ktoe reduction in energy use and a 12.4 $MtCO_2$ reduction in 2030. The Department of Energy in Philippines also plans to expand renewable energy generation, aiming to reach installed capacity levels in 2030 (compared to 2010) of 7,534 MW hydropower (3,478 MW in 2010); 1,018 MW wind (33 MW in 2010); 85 MW solar (6.7 MW in 2010); 93.9 MW biomass (75.5 MW in 2010); and 3,447 MW geothermal (1,972 MW in 2010), for a total installed capacity of 12,084 MW from renewable sources, and more than double the total renewable capacity in 2010. The Renewable Energy Coalition has estimated the total potential renewable capacity in Philippines as 4,531 MW geothermal; 13,097 MW hydroelectric; 76,600 MW wind; 170,000 MW wave; 277 million barrels fuel oil equivalent per year biomass; and 5 KWh per square meter per day of solar (CCC, 2011).

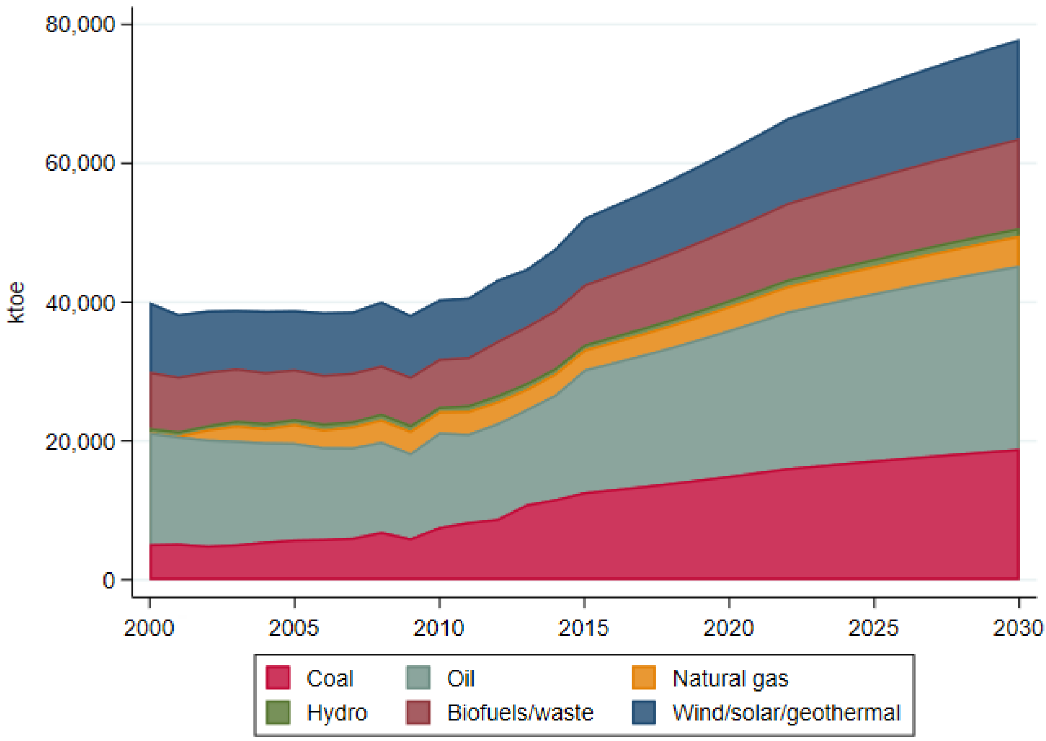

Figure 5.7.2. Philippines Total Primary Energy Supply (TPES)

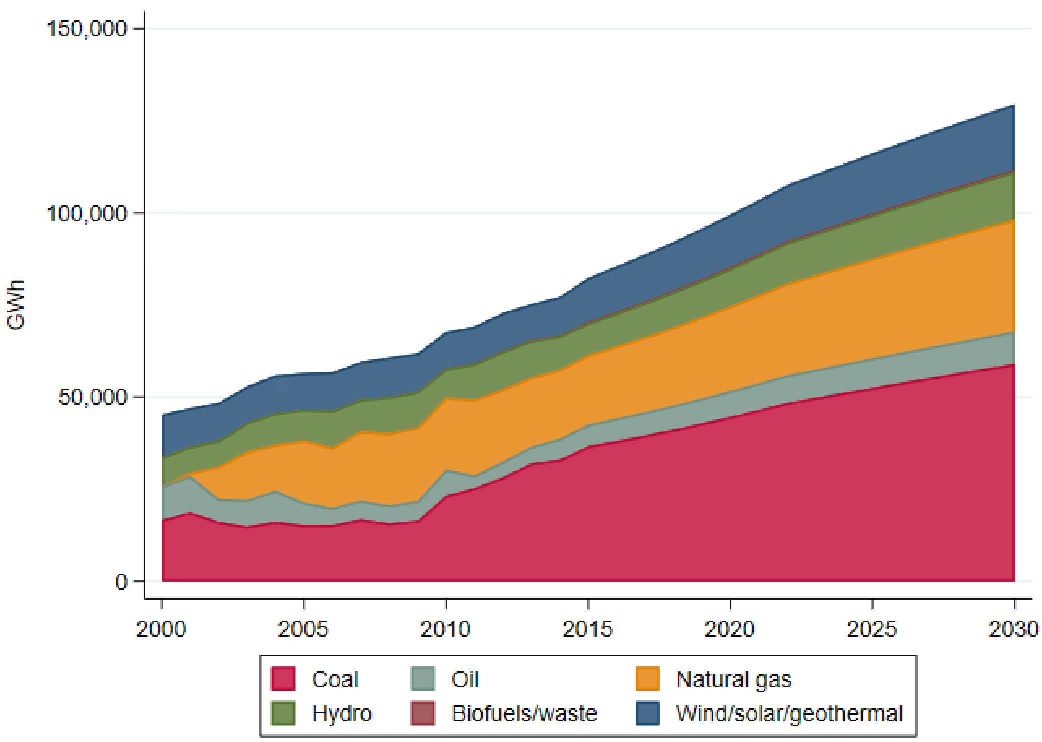

Figure 5.7.3. Philippines electricity generation

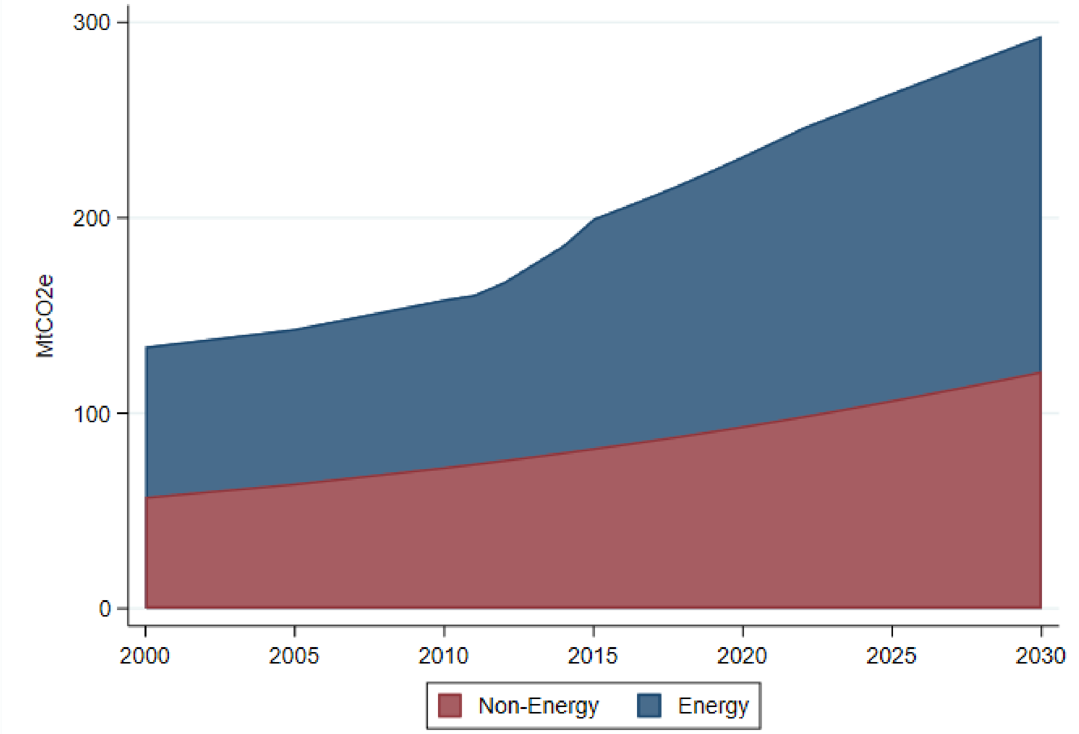

Figure 5.7.4. Philippines sectoral emissions

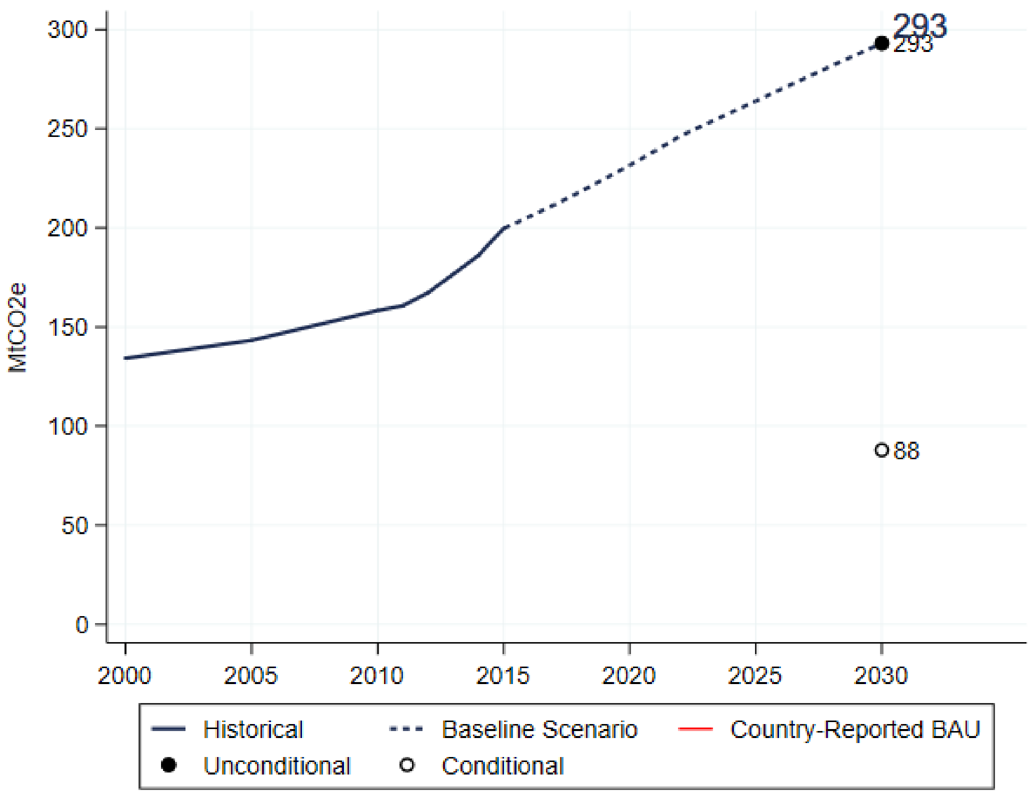

Figure 5.7.5. Philippines total emissions

Table 5.7.1. Policies and technologies declared in the Philippines" NDC

Type	NDC Reference
Declared Policies	Ecological Solid Waste Management Act (2000)
	Biofuels Act (2006)
	Renewable Energy Act (2008)
	National Framework Strategy on Climate Change (NFSCC) (2010)
	National Climate Change Action Plan (NCCAP) (2011)
	Climate Change Act (2009, amended 2012)
	Philippine Biodiversity Strategy and Action Plan
Declared Technologies	Renewable energy
	Energy-efficient power generation technology
	Grid efficiency improvements

Table 5.7.2. Fuel shares and generation ratios for Philippines

	Coal	Oil	Natural gas	Hydro	Geothermal/ solar/wind	Biofuels/ waste
2015: TPES Share	0.24	0.34	0.06	0.01	0.18	0.17
2015: Ratio - generation to TPES (GWh/ktoe)	2.90	0.33	6.57	11.63	1.25	0.04
Source: Calculations using IEA (2017a)						

Table 5.7.3. Projected growth rates for Philippines

	Average Annual Growth Rates
GDP (2023–2030)	5.36%
TPES per GDP (2016–2030)	-3.19%
Population (2016–2030)	1.59%

Source: Calculations using IEA (2017a), IMF (2017), and UN (2017)

5.8 Singapore

Figure 5.8.1. Map of Singapore

Singapore is a small island and Southeast Asian city-state at the southern tip of the Malay Peninsula. It opens to the Singapore Strait in the south and borders the country of Malaysia across the Johor Strait to the north.

According to UN (2017), Singapore had a population of 5.5 million people in 2015, or 0.87% of the total population in the ASEAN region. Singapore's population grew an average of 2.34% annually from 2000 to 2015 (compared to the ASEAN rate of 1.27%) and is projected to grow at an average annual rate of 0.91% from 2016 through 2030 (approximately matching the predicted ASEAN rate of 0.92%).

In 2015 the GDP of Singapore was 394 billion 2010 Singapore dollars (297 billion USD). The country experienced an average annual growth rate of 5.24% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 2.65% average annual growth rate of GDP for 2016 to 2030.

Below we present our projections for energy supply, electricity generation, and GHG emissions in Singapore. We also describe Singapore's NDC targets and highlight some of the technologies and policies Singapore has referenced to meet its commitments. Tables summarizing modeling assumptions for Singapore are included at the end of this section.

Data on TPES and generation in Singapore for years 2000 to 2015 is sourced from IEA (2017a). We project that TPES in 2030 will total 25,674 ktoe with 60% from oil, 36% from natural gas, 3% from biofuels and waste, less than 2% from coal, and less than 1% from other non-hydro renewables. Electricity generation is projected to reach 54,318 GWh in 2030 with a generation mix of 95% natural gas, 3% biofuels and waste, 1% coal, less than 1% oil, and less than 1% other non-hydro renewables.

As a global trading hub with a high trade to GDP ratio, Singapore experiences volatility in import and export data due to the large and volatile trade volumes. Our calculations do not reflect annual variability. Feedstock inputs to a refinery process contribute a substantial share of oil use in Singapore. Thus, TPES is not an accurate representation of domestic energy consumption. The adjustments for feedstock use in Singapore are described in Appendix B.

Data for GDP in Singapore (in 2010 Singapore dollars) is taken from IMF (2017). Based on historical trends from 2009 to 2015, we project that energy intensity of GDP in Singapore will show an average annual decline of 2.57% and reach 44.0 ktoe per billion 2010 Singapore dollars by 2030. Singapore is among the most energy-efficient economies; therefore, continuing the same rate of average annual decline in energy intensity might be challenging. With an assumption of a lower future rate of annual decline, emission projections would be higher than our current Baseline estimates. See Appendix C for figures illustrating energy intensity of GDP as well as emission intensity of TPES over time.

In the Baseline scenario, Singapore is projected to emit 51.4 $MtCO_2$ in the year 2030, with energy sector GHG emissions contributing 96% of total GHG emissions in 2030 (see Figure 5.8.4). In its NDC, Singapore pledges to reduce its emissions intensity of GDP by 36% in 2030 relative to 2005, which corresponds to an estimated emissions target of 65.0 $MtCO_2$ in 2030, or 26% more than in the projected Baseline trajectory. Climate Action Tracker (climateactiontracker.org) similarly finds that Singapore will overachieve its NDC target in the BAU scenario on the basis of total emissions.

The country's plan for achieving its energy intensity goals is described in its 2012 National Climate Change Strategy (NCCS), with energy efficiency identified as the core strategy. The report identifies several sector-based mitigation measures with the expectation that half of emission reductions come from the power generation sector, about 10–16% each from the industry, transport, households, and building sectors, and less than 3% each from the water and waste management sectors. The NCCS also identifies broad fiscal, capability-building, and regulatory tools as policy responses to a variety of anticipated challenges, including high investment costs and split incentives. For power generation, Singapore is exploring the potential of solar energy by investing in technology R&D, solar test beds, and solar power business models to enhance the feasibility of solar generation on a larger scale.

In the industrial sector, the Design for Efficiency Scheme and the Energy Efficiency Improvement Assistance Scheme assist with the upfront cost of energy efficiency investments in new and existing facilities. The Energy Conservation Act of 2013 requires energy-intensive industries (users that consume more than 15 GWh of energy per year) to implement energy management practices. In the buildings sector, the Building Control Regulation requires new and retrofit buildings with a floor area of at least 2,000 square meters to be Green Mark-compliant by achieving 28% energy efficiency improvements over the 2005 building codes, with the option of pursuing higher-tier Green Mark ratings. For transportation, Singapore is in part targeting the use of public transit for 70% of trips by 2020 compared to 59% in 2008

Singapore has also recently introduced its plan to implement a carbon tax beginning in 2019. The tax covers six GHGs—CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6—and will apply to facilities emitting at least 25 $ktCO_2e$ per year. The tax will begin at \$5 per tCO_2e for emissions in 2019 and is intended to increase to \$10 to \$15 per tCO_2e by 2030 (NCCS, 2018).

As a result of these emission mitigation activities, Singapore projects in its NDC that its emissions intensity of GDP will decline by 2.5% annually from 2021 to 2030, compared to the country-reported 1.5% annual decline from 2005 to 2020 and the 2.5% annual decline modeled in our Baseline trajectory for 2016 to 2030. In the process of achieving its 2030 targets, Singapore aims to reduce its total emissions by 16% in 2020 relative to its BAU with an expectation that total emissions will stabilize with the aim of peaking around 2030.

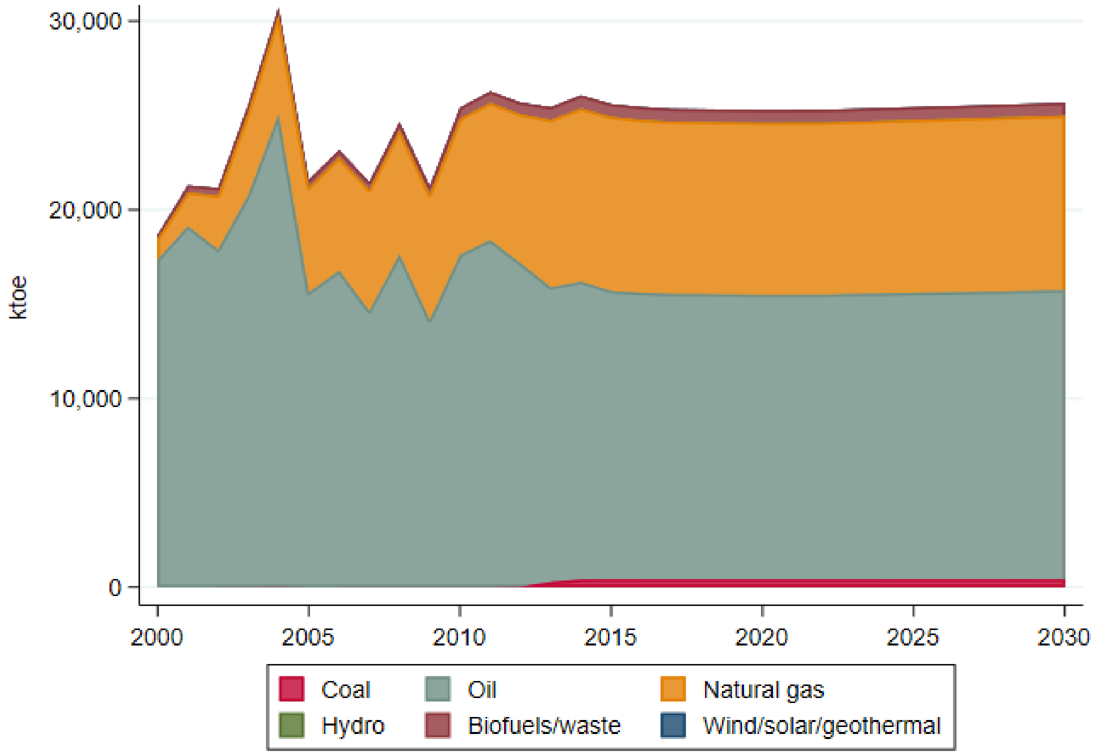

Figure 5.8.2. Singapore Total Primary Energy Supply (TPES)

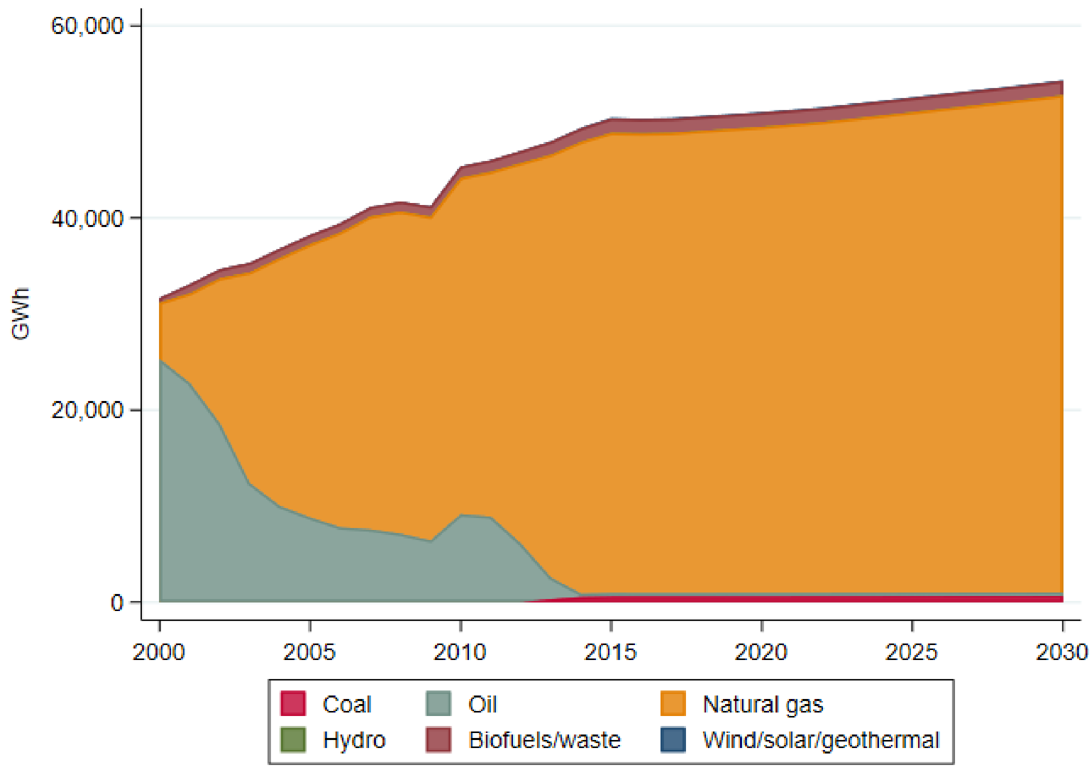

Figure 5.8.3. Singapore electricity generation

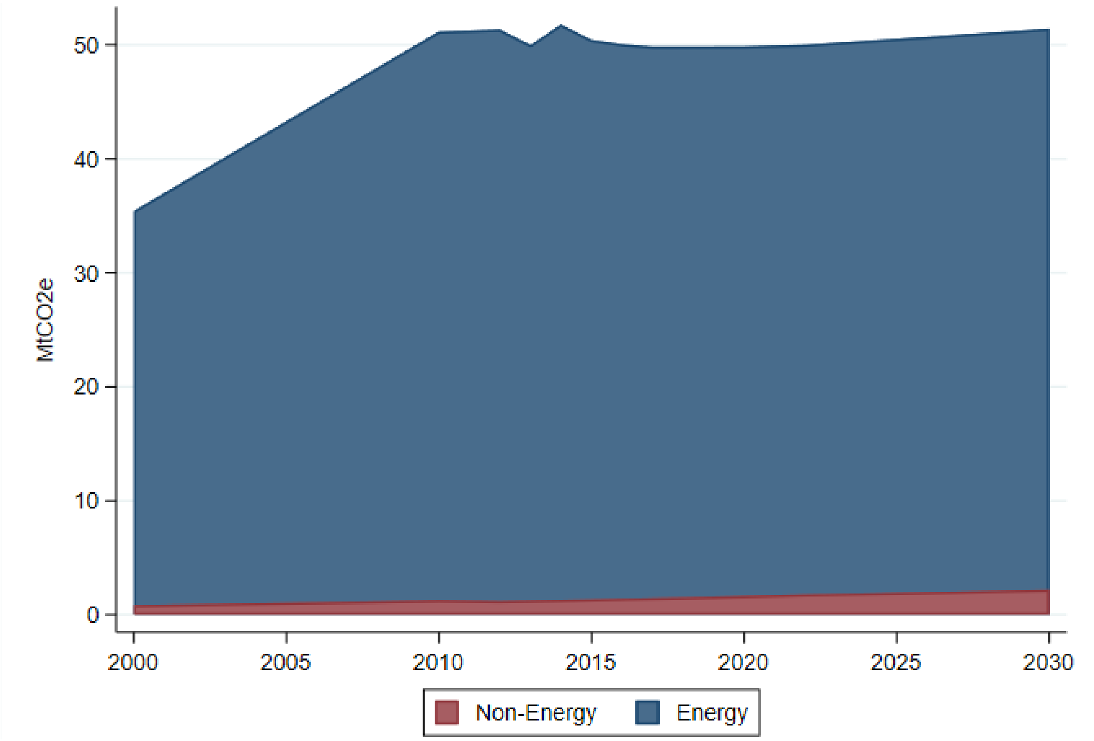

Figure 5.8.4. Singapore sectoral emissions

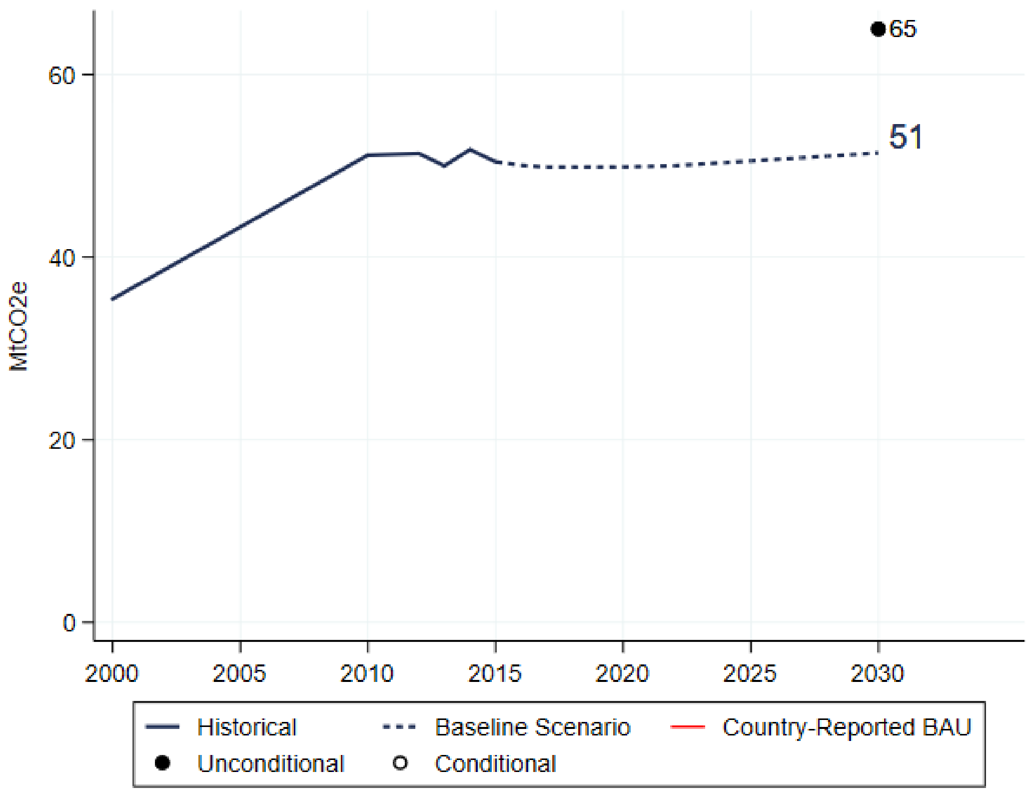

Figure 5.8.5. Singapore total emissions

Table 5.8.1. Policies and technologies declared in Singapore's NDC

Type	NDC Reference
Declared Policies	National Climate Change Strategy (2012)
	Sustainable Singapore Blueprint (2015)
Declared Technologies	Solar PV deployment
	Energy-efficient technologies across all sectors

Table 5.8.2. Fuel shares and generation ratios for Singapore

	Coal	Oil	Natural gas	Hydro	Geothermal/ solar/wind	Biofuels/ waste
2015: TPES Share	0.02	0.60	0.36	--	0.00	0.03
2015: Ratio - generation to TPES (GWh/ktoe)	1.48	0.02	5.19	--	11.63	2.19
Source: Calculations using IEA (2017a)						

Table 5.8.3. Projected growth rates for Singapore

	Average Annual Growth Rates
GDP (2023–2030)	2.82%
TPES per GDP (2016–2030)	-2.57%
Population (2016–2030)	1.62%

Source: Calculations using IEA (2017a), IMF (2017), and UN (2017)

5.9 Thailand

Figure 5.9.1. Map of Thailand

Thailand is a Southeast Asian country centered on the Indochina Peninsula and extending south onto the Malay Peninsula. Thailand borders Lao PDR to the northeast, Cambodia to the southeast, Myanmar to the west and northwest, and Peninsular Malaysia to the south. The Thai capital city Bangkok faces south out to the Gulf of Thailand, which the country enfolds on the eastern side of the Malay Peninsula.

According to UN (2017), Thailand had a population of 68.7 million people in 2015, or 10.8% of the total population in the ASEAN region. Thailand's population grew an average of 0.58% annually from 2000 to 2015, compared to the ASEAN rate of 1.27%, and the lowest rate of the ten ASEAN countries. Thailand's population growth rate is projected to slow further to an average annual rate of 0.08% from 2016 through 2030 (compared to the ASEAN rate of 0.92%).

In 2015 the GDP of Thailand was 9.5 trillion 2002 Thai baht (399 billion current USD). The country experienced an average annual growth rate of 4.03% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 3.27% average annual growth rate of GDP for 2016 to 2030.

Below we present our projections for energy supply, electricity generation, and GHG emissions in Thailand. We also describe Thailand's NDC targets and highlight some of the technologies and policies Thailand has referenced to meet its commitments. Tables summarizing modeling assumptions for Thailand are included at the end of this section.

Data on TPES and generation in Thailand for years 2000 to 2015 is sourced from IEA (2017a). We project that TPES in 2030 will total 223,909 ktoe with 40% from oil, 28% from natural gas, 19% from biofuels and waste, 13% from coal, and less than 1% from hydro and other renewables. Electricity generation is projected to reach 317,579 GWh in 2030 with a generation mix of 72% natural gas, 20% coal, 7% renewables, and less than 1% oil.

Data for GDP in Thailand (in 2002 Thai baht) is taken from IMF (2017). Based on historical trends from 2000 to 2015, we project that energy intensity of GDP in Thailand will show an average annual increase of 0.2% and reach 14.5 ktoe per billion 2002 baht by 2030. See Appendix C for figures illustrating energy intensity of GDP as well as emission intensity of TPES over time.

In the Baseline scenario, Thailand is projected to emit 645 $MtCO_2e$ excluding LULUCF emissions in the year 2030, with emissions from fossil fuel combustion contributing 84.7% of total GHG emissions. In its NDC, Thailand pledges to reduce total GHG emissions by 20% in 2030 relative to its BAU and by 25% conditional on international financial support. These commitments yield GHG emission targets of 516 $MtCO_2e$ unconditionally and 484 $MtCO_2e$ conditionally in 2030. In comparison, in its NDC Thailand reports expected BAU emissions of 555 $MtCO_2e$ in 2030, which corresponds to an unconditional target of 444 $MtCO_2e$ and a conditional target of 416 $MtCO_2e$.

Thailand specifies in its NDC that 73% of emissions in 2012 came from the energy and thus is focusing its mitigation efforts on the energy and transport sectors. Thailand's Power Development Plan (PDP) aims for renewable sources to make up 20% of total generation in 2036, up from 8.5% in 2015 per data from IEA (2017a). Similarly, the Alternative Energy Development Plan (AEDP) sets a target of 30% of TPES to come from renewable sources by 2036 compared to 19% in 2015 from IEA (2017a). These targets would be met through an expansion in total generating capacity from 37,612 MW in 2014 to 70,335 MW in 2036, of which renewables would expand from 7,490 MW in 2014 to 19,634 MW in 2036 (Thailand Ministry of Energy, 2015). In this expansion, energy crops emerge as a new fuel source, while growth in solar generation accounts for 41% of the remaining renewables growth. Wind and biomass are each responsible for about 25% of this growth, with the remaining supplied by hydro, waste, and biogas.

Furthermore, Thailand's Energy Efficiency Development Plan (EEDP) supports a 30% reduction in energy intensity of GDP in 2036 relative to 2010, with 85% of anticipated savings occurring in the thermal sectors (44,059 ktoe) and 15% of savings in the electricity sector (7,641 ktoe or 89,672 GWh) (Thailand Ministry of Energy, 2015). Nearly half of electricity sector savings in 2036 come from measures addressing Specific Energy Consumption (SEC), High Energy Performance Standards (HEPs) and Minimum Energy Performance Standards (MEPs) with the remainder coming from monetary incentives, building energy codes, LED promotion, and Energy Efficiency Resource Standards (EERS). Broken down into economic sectors, about 40% of electricity savings come from businesses, 36% from industry, and the remainder from residential, agriculture, and government sectors.

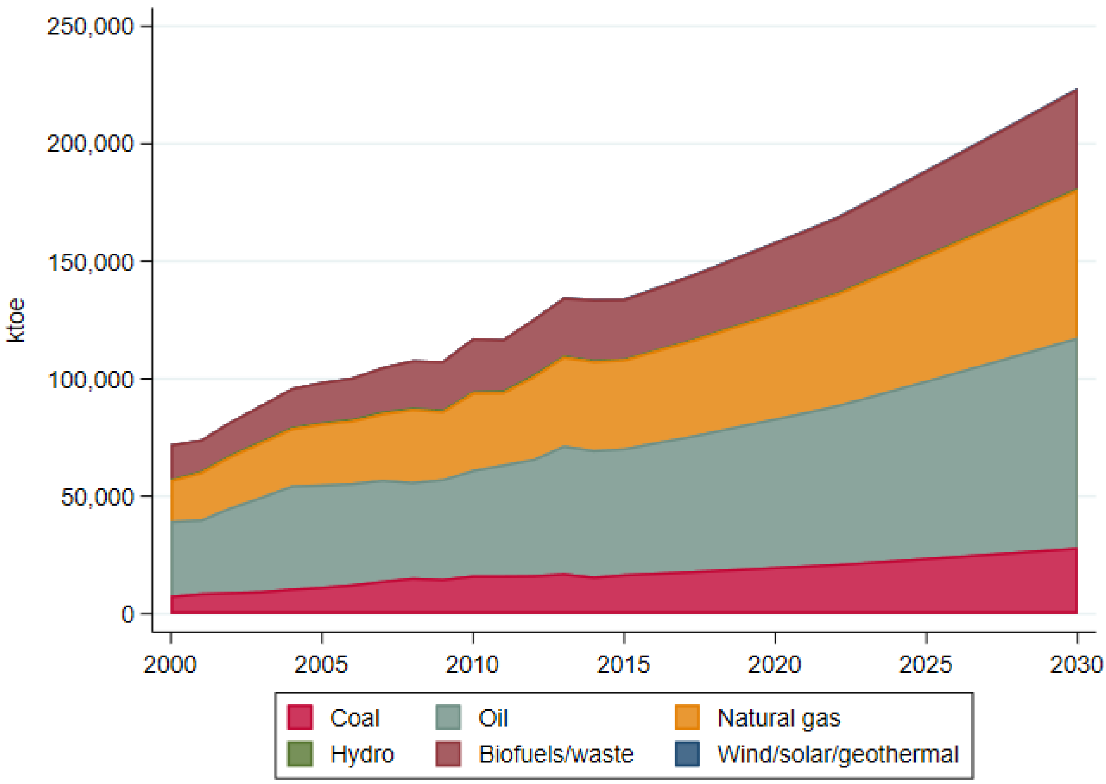

Figure 5.9.2. Thailand Total Primary Energy Supply (TPES)

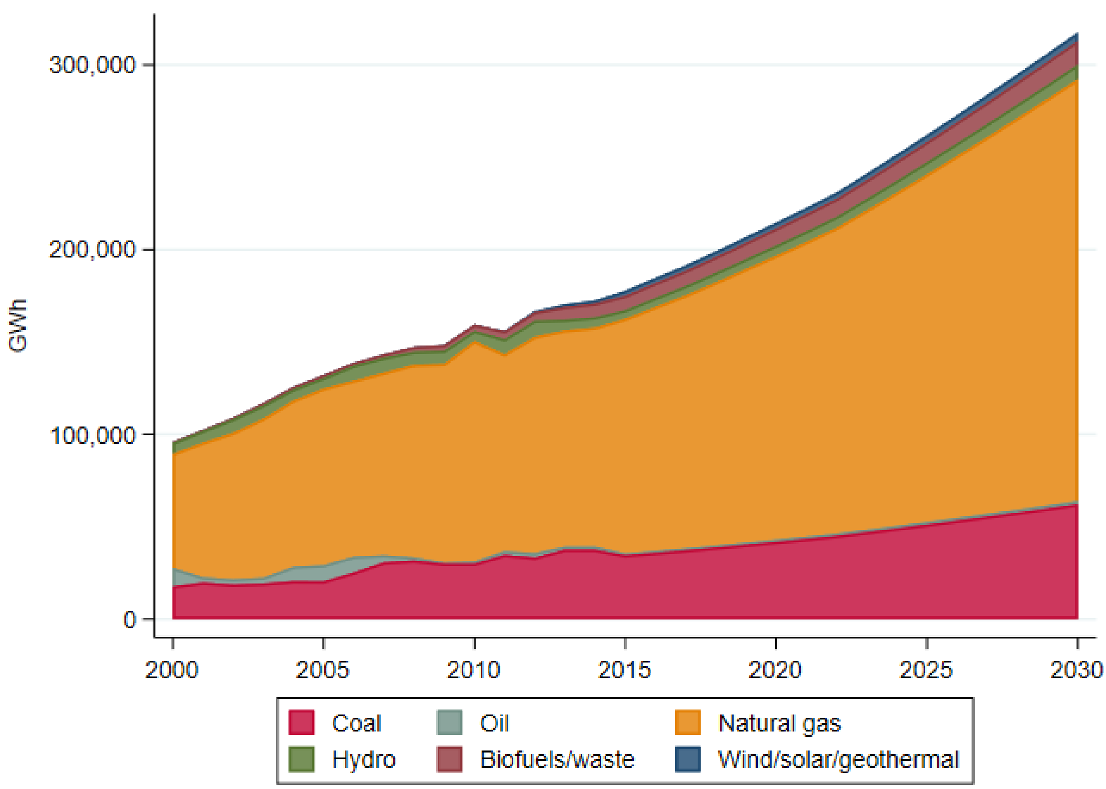

Figure 5.9.3. Thailand electricity generation

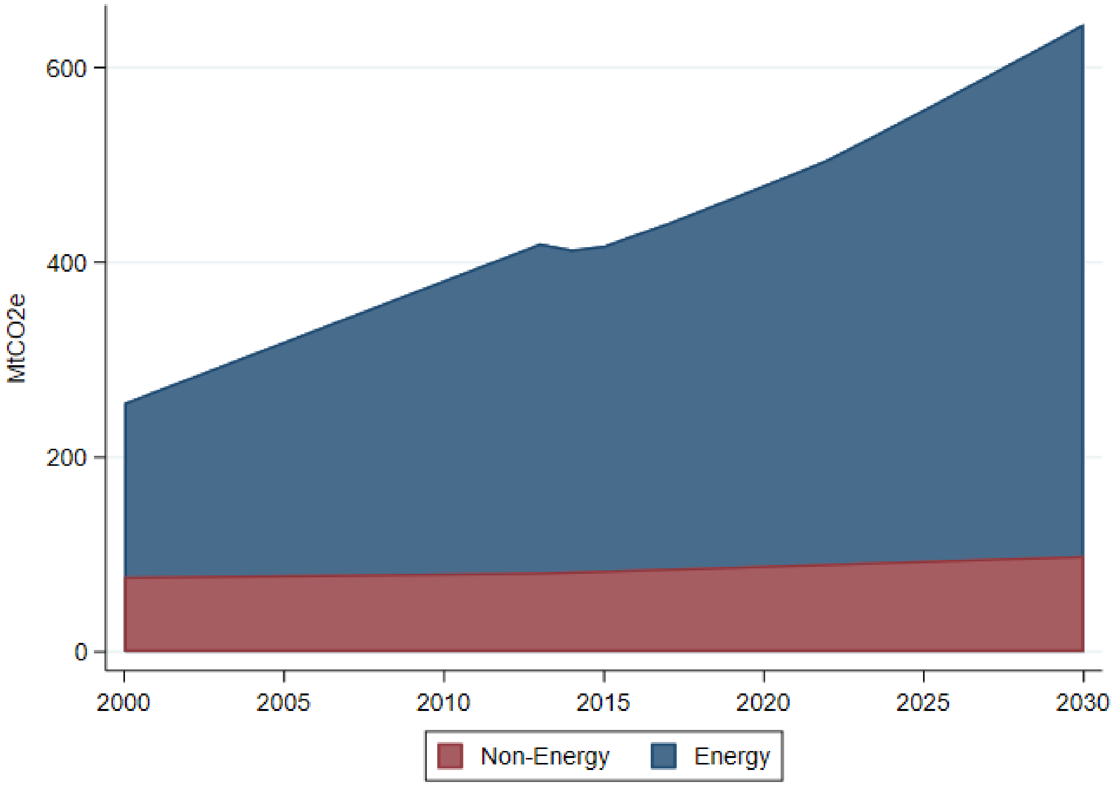

Figure 5.9.4. Thailand sectoral emissions

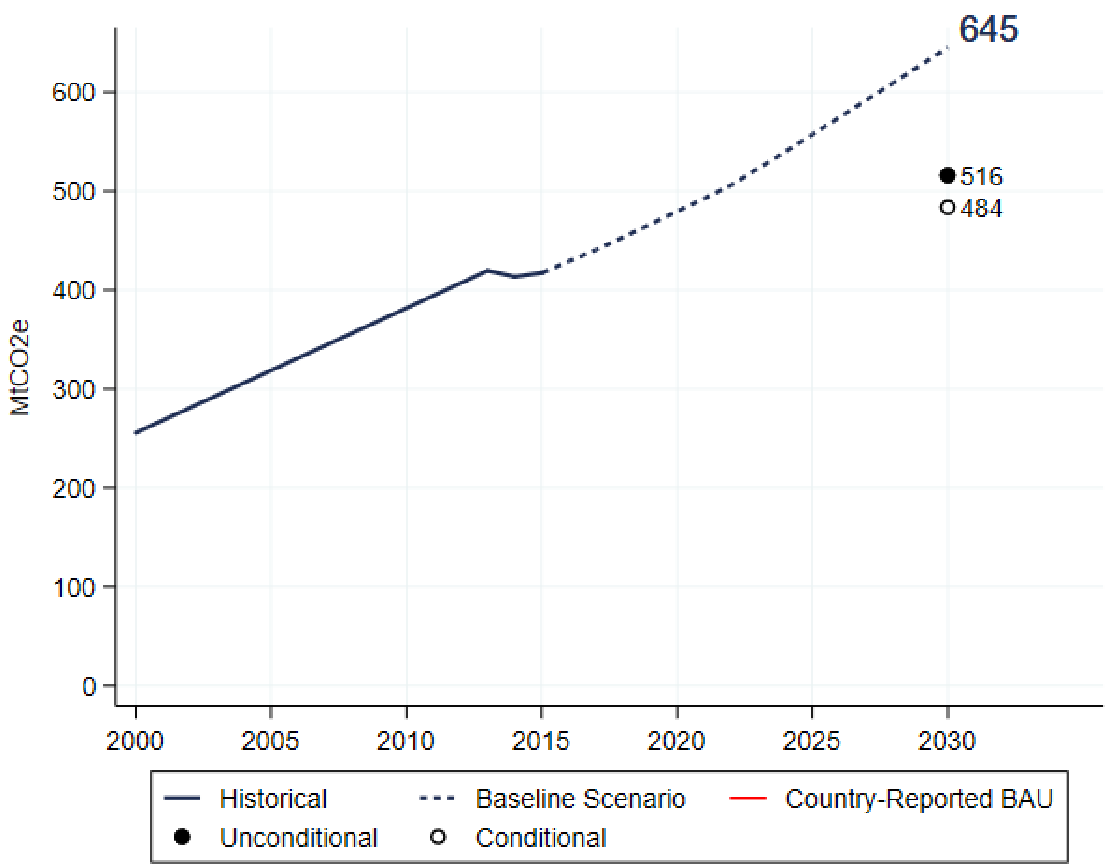

Figure 5.9.5. Thailand total emissions

Table 5.9.1. Policies and technologies declared in Thailand's NDC

Type	NDC Reference
Declared Policies	Climate Change Master Plan for 2015–2050
	Power Development Plan (PDP) for 2015–2036
	Thailand Smart Grid Development Master Plan for 2015–2036
	Energy Efficiency Plan (EEP) for 2015–2036
	Alternative Energy Development Plan (AEDP) for 2015–2036
	Environmentally Sustainable Transport System Plan for 2013–2030
	National Industrial Development Master Plan for 2012–2031
	Waste Management Roadmap
Declared Technologies	Renewable energy generation and consumption
	Freight and passenger transport (mass rapid transit lines, double-track railways, bus transit improvements)
	Waste-to-energy technologies

Table 5.9.2. Fuel shares and generation ratios for Thailand

	Coal	Oil	Natural gas	Hydro	Geothermal/ solar/wind	Biofuels/ waste
2015: TPES Share	0.13	0.40	0.28	0.00	0.00	0.19
2015: Ratio - generation to TPES (GWh/ktoe)	2.05	0.02	3.36	11.63	11.59	0.31
Source: Calculations using IEA (2017a)						

Table 5.9.3. Projected growth rates for Thailand

	Average Annual Growth Rates
GDP (2023–2030)	3.39%
TPES per GDP (2016–2030)	0.20%
Population (2016–2030)	0.34%

Source: Calculations using IEA (2017a), IMF (2017), and UN (2017)

5.10 Vietnam

Figure 5.10.1. Map of Vietnam

Vietnam is a Southeast Asian country forming the eastern coast of the Indochina Peninsula. It borders China to the north and Lao PDR and Cambodia to the west. Vietnam's eastern coast borders the South China Sea, and a smaller section of coastline faces the Gulf of Thailand to the west. Vietnam's capital city Hanoi is situated in the northernmost section of the country.

According to UN (2017), Vietnam had a population of 93.6 million people in 2015, or 14.8% of the total population in the ASEAN region. Thailand's population grew an average of 1.03% annually from 2000 to 2015 (compared to the ASEAN rate of 1.27%) and is projected to grow at an average annual rate of 0.85% from 2016 through 2030 (compared to the ASEAN rate of 0.92%).

In 2015 the GDP of Vietnam was 2,876 trillion 2010 Vietnamese dong (191 billion USD). The country experienced an average annual growth rate 6.52% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 6.17% average annual growth rate of GDP for 2016 to 2030.

Below we present our projections for energy supply, electricity generation, and GHG emissions in Vietnam. We also describe Vietnam's NDC targets and highlight some of the technologies and policies Vietnam has referenced to meet its commitments. Tables summarizing modeling assumptions for Vietnam are included at the end of this section.

Data on TPES and generation in Vietnam for years 2000 to 2015 is retrieved from IEA (2017a). We project that TPES in 2030 will total 178,313 ktoe with 34% from coal, 26% from oil, 21% from biofuels and waste, 13% from natural gas, 4% from hydro, and 2% from other renewables. Electricity generation is projected to reach 375,957 GWh in 2030 with a generation mix of 36% natural gas, 32% coal, 24% hydro, 9% geothermal/solar/wind, and less than 1% of oil and biofuels.

Data for GDP in Vietnam (in 2010 Vietnamese dong) is taken from IMF (2017). Based on historical trends from 2000 to 2015, we assume that energy intensity of GDP in Vietnam will show little change on average and equal 0.025 ktoe per billion 2010 dong in 2030. See Appendix C for figures illustrating energy intensity of GDP as well as emission intensity of TPES over time.

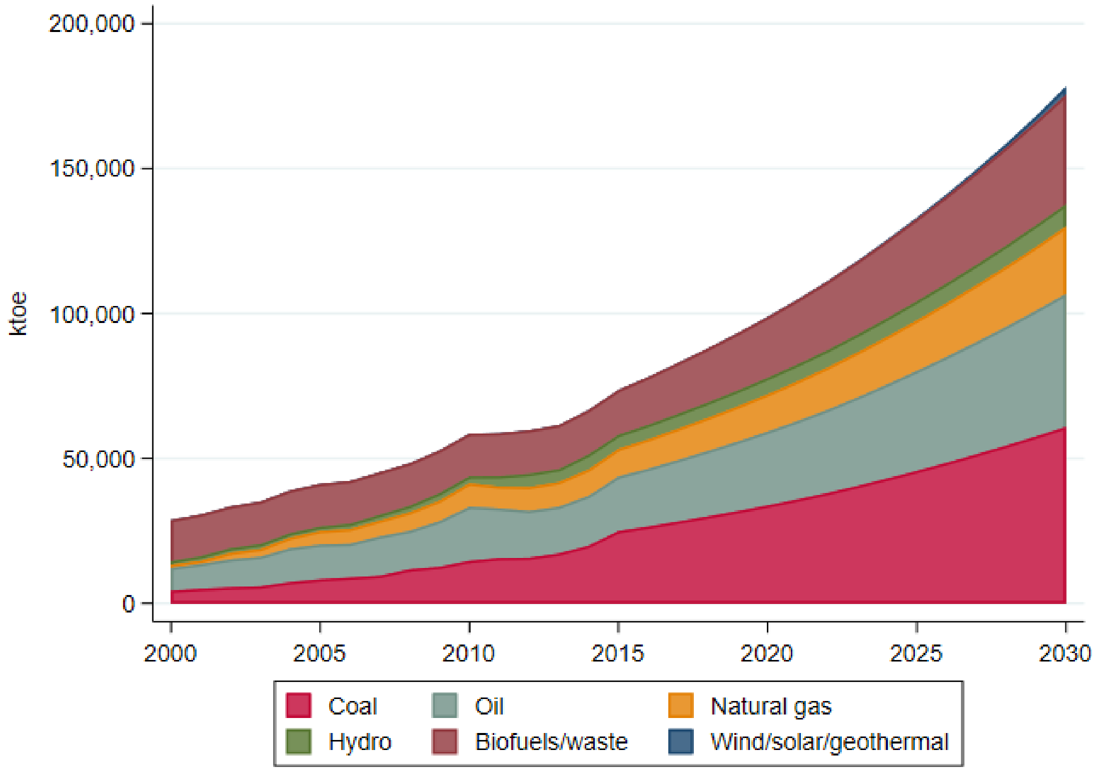

Figure 5.10.2. Vietnam Total Primary Energy Supply (TPES)

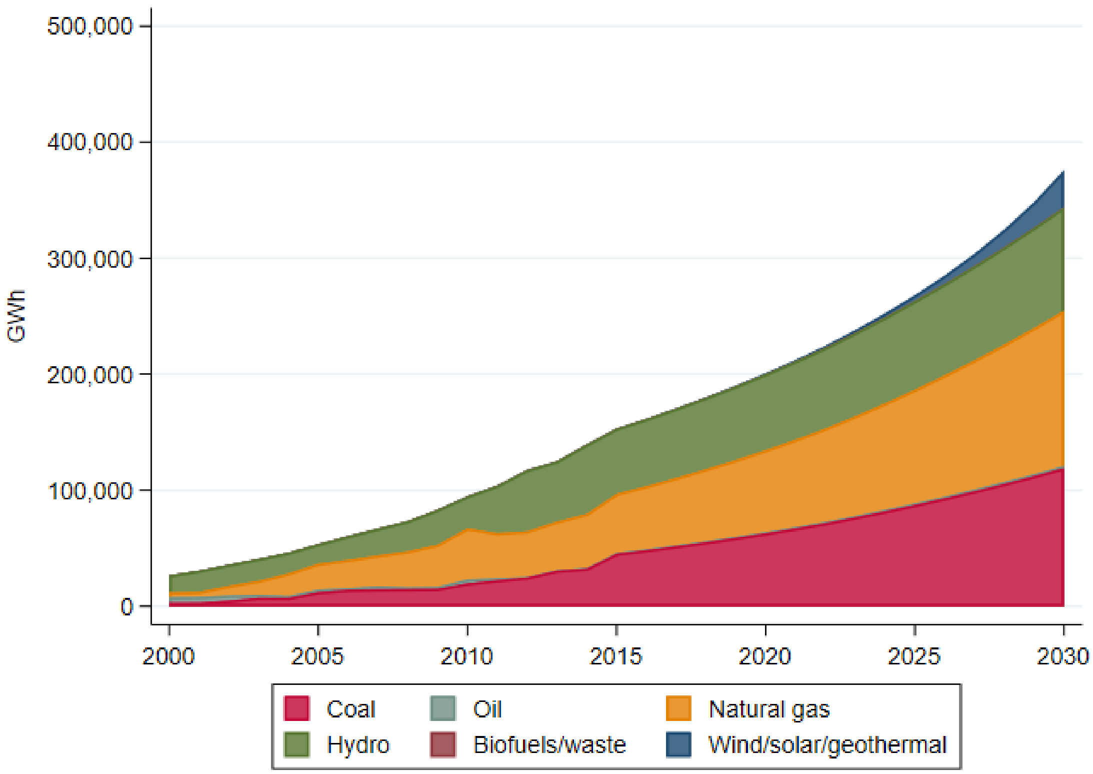

Figure 5.10.3. Vietnam electricity generation

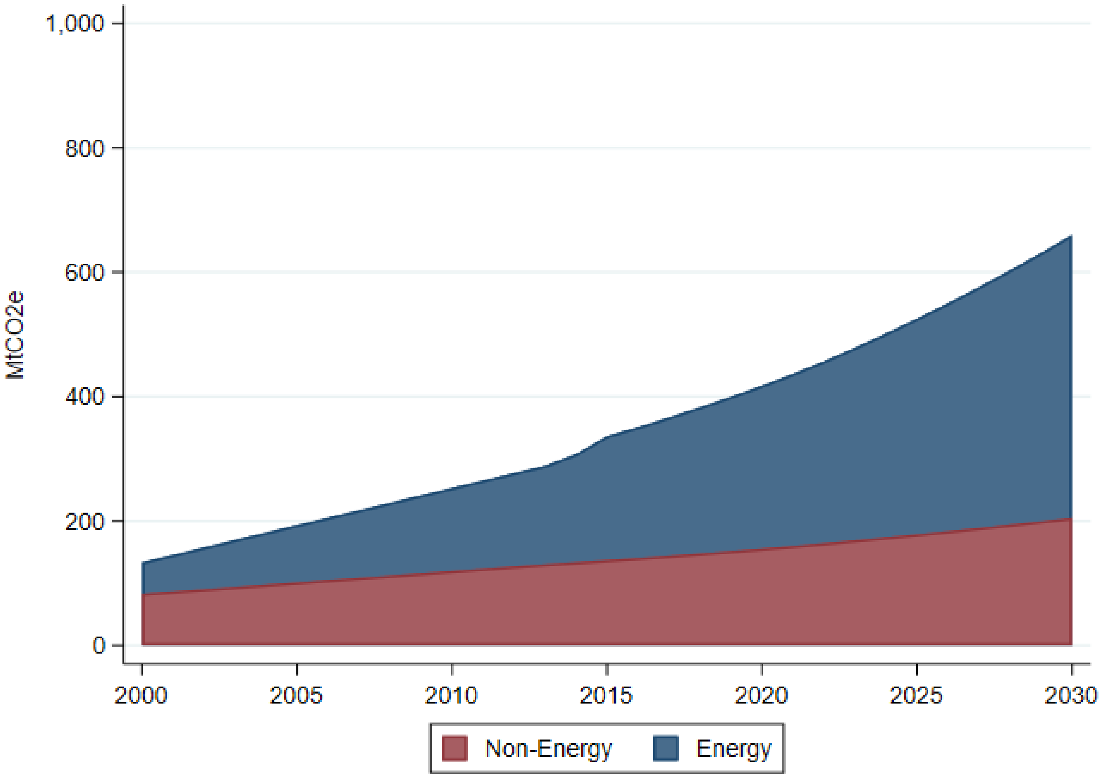

Figure 5.10.4. Vietnam sectoral emissions

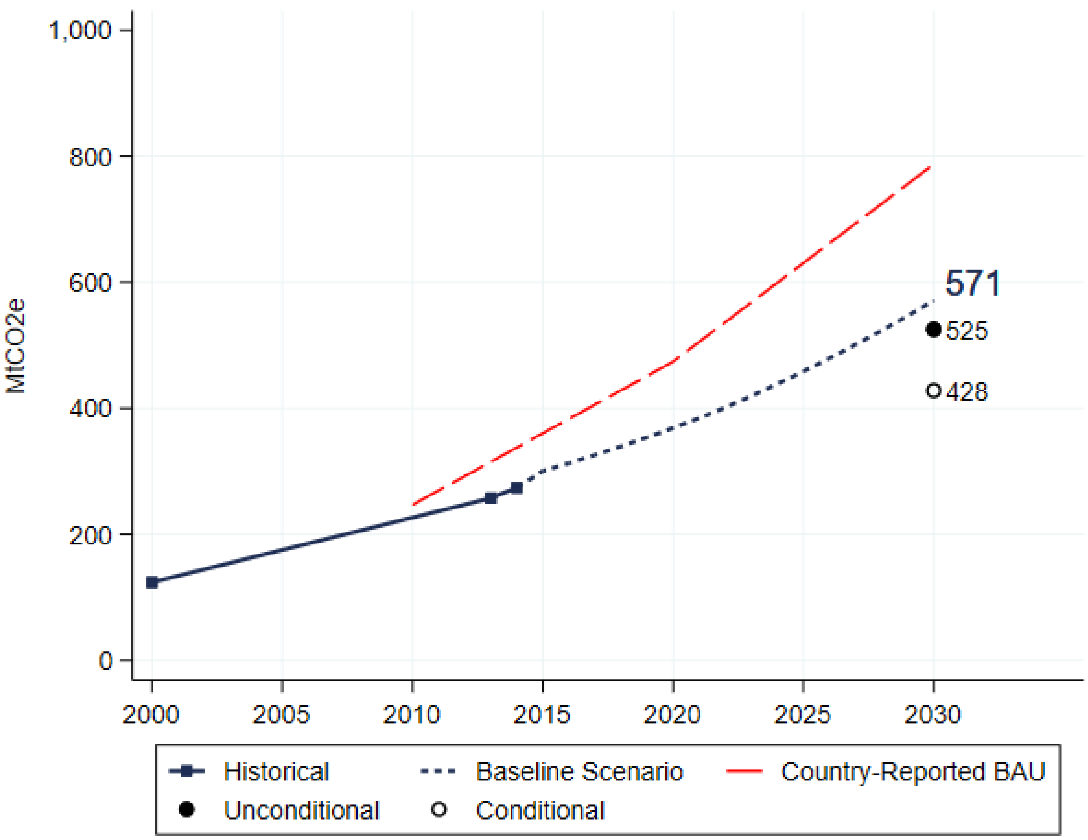

Figure 5.10.5. Vietnam total emissions

In the Baseline scenario, Vietnam is projected to emit 571 $MtCO_2e$ in the year 2030, with energy emissions contributing 69% of total GHG emissions (as in Figure 10.2.4). However, in this Baseline scenario (illustrated in Figure 10.2.5) we exclude industrial emissions, equal to 92 $MtCO_2e$ in 2030, to align with the scope specified in the NDC. In its NDC, Vietnam pledges to reduce total GHG emissions by 8% in 2030 relative to its BAU and by 25% conditional on international financial support. Additionally, the country pledges to reduce its emissions intensity of GDP by 20% in 2030 relative to 2005 and by 30% conditional on international financial support. Vietnam's commitment to reduce total GHG emissions yields the targets of 525 $MtCO_2e$ unconditionally and 428 $MtCO_2e$ conditionally in 2030. In comparison, in its NDC Vietnam provides a 2030 BAU emission estimate of 787.4 $MtCO_2e$, which excludes industrial processes but includes LULUCF emissions, and leads to target emissions of 724 $MtCO_2e$ unconditionally and 591 $MtCO_2e$ conditionally per Vietnam's total GHG pledges.

We also consider policy targets applied to an *alternative* reference scenario (Baseline B) constructed in resemblance of generation output levels for the year 2030 specified in Vietnam's Revised Power Development Plan. In this plan, Vietnam lays out its goal to achieve 10% renewables in electricity generation in 2030 excluding large-scale hydro and to further develop the automation of the power transmission grid so as to increase generation and distribution capabilities. The fastest growth in renewables capacity would come from solar power plants (12,000 MW in 2030, up from zero capacity in 2020) (GIZ, 2016). However, much of the increase in generation will come from coal (GDE, 2017). Table 5.10.1 summarizes the difference in generation in 2030 by fuel in the alternative Baseline scenarios while Figure 5.10.6 illustrates the alternative, modeled generation mix out to 2030. In MIT's Baseline B for Vietnam, we estimate total generation of 533,000 GWh and economy-wide emissions of 929 $MtCO_2e$, compared to 375,957 GWh and 571 $MtCO_2e$ in the original "Baseline A" scenario. Applying Vietnam's policy goals relative to 2030 in Baseline B yields an unconditional emissions target of 855 $MtCO_2e$ in 2030 (compared to 525 $MtCO_2e$ in Baseline A), or 697 $MtCO_2e$ (428 $MtCO_2e$ in Baseline A) conditional on financial support. Emission targets for Vietnam in Baseline B are illustrated in Figure 5.10.7.

Table 5.10.1. Vietnam's generation in 2030 in alternative Baseline scenarios

Scenario	Generation in 2030 (GWh)						
	Coal	*Oil*	*Natural Gas*	*Hydro*	*Biofuels /waste*	*Other renewables*	*Total*
A	119,164	1,817	133,828	89,000	146	32,000	375,957
B	304,000	0	96,000	89,000	12,000	32,000	533,000

To achieve its targeted emission reductions, Vietnam outlines in its NDC a range of mitigation measures related to energy production, industry, agriculture, transportation, and waste management. Additionally, as of June 2015, Vietnam had registered 254 Clean Development Mechanism projects, of which 88% of projects were in energy, 10% in waste management, and 2% in land use and others (VNEEP, 2016). We provide an economy-wide analysis of meeting Vietnam's targets in Section 6.

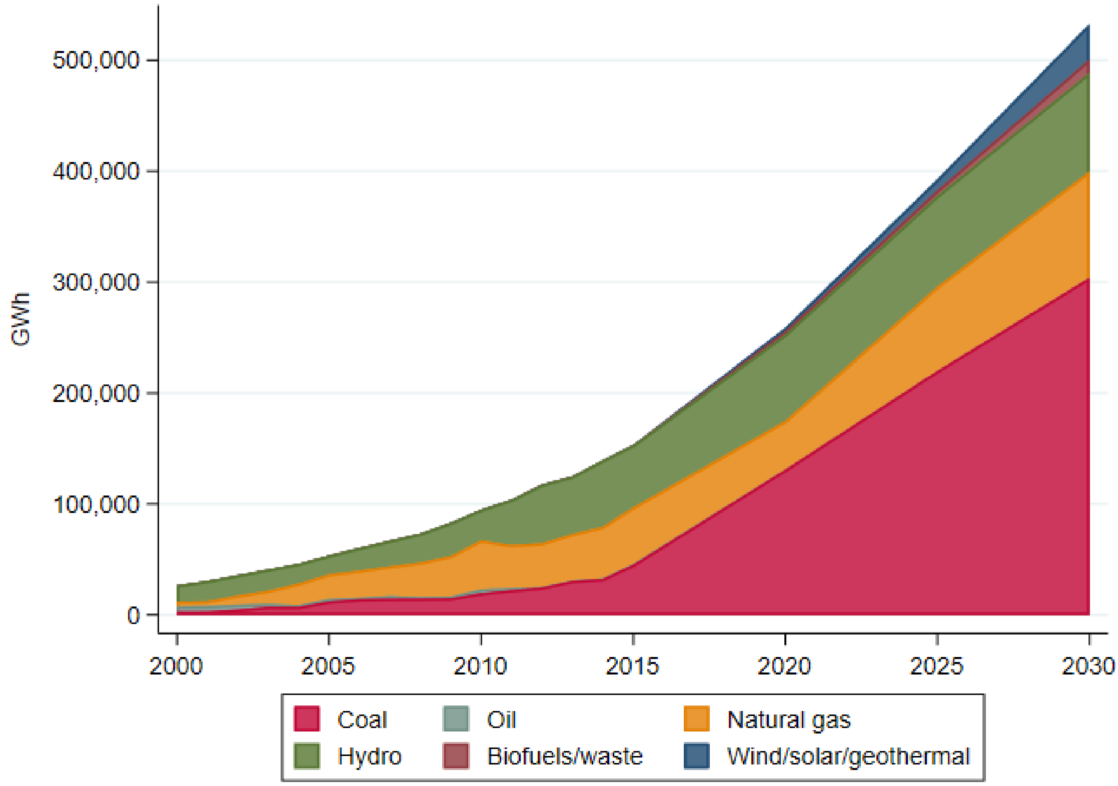

Figure 5.10.6. Vietnam electricity generation in alternative Baseline B

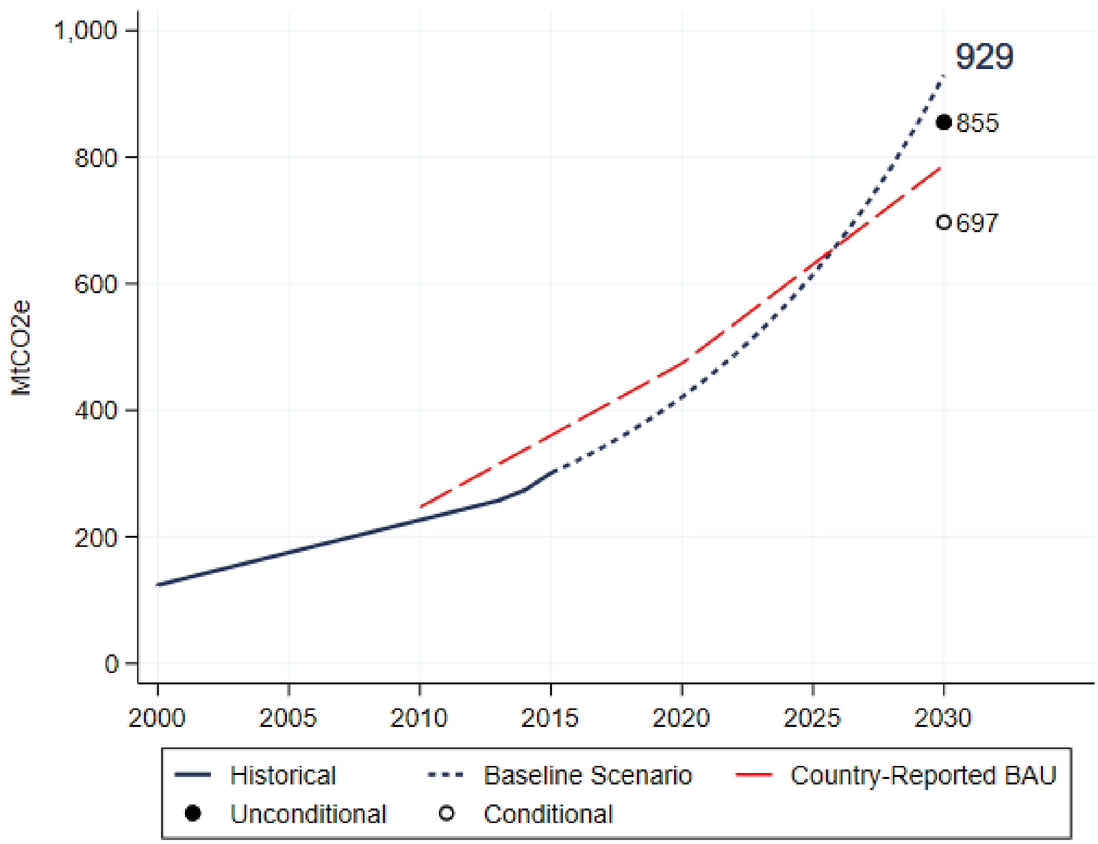

Figure 5.10.7. Vietnam total emissions in alternative Baseline B

Table 5.10.2. Policies and technologies declared in Vietnam's NDC

Type	NDC Reference
Declared Policies	National Target Programme on Energy Efficiency (2006)
	National Target Programme to Respond to Climate Change (NTP-RCC) (2008)
	Law on Economical and Efficient Use of Energy (2010)
	National Climate Change Strategy (2011) for 2011–2015 and 2016–2050
	National Green Growth Strategy (2012)
	Law on Environment (2014)
	Socio-Economic Development Plan for 2011–2015
Declared Technologies	Renewable energy generation
	Energy-efficient technologies in residential, trade, and service sectors
	Urban public transit
	Technologies for sustainable agriculture (production and waste)
	Waste treatment technologies, incl. power generation from landfill gas
	254 Clean Development Mechanism (CDM) projects

Table 5.10.3. Fuel shares and generation ratios for Vietnam

	Coal	Oil	Natural gas	Hydro	Geothermal/ solar/wind	Biofuels/ waste
2015: TPES Share	0.34	0.26	0.13	0.07	0.00	0.21
2015: Ratio - generation to TPES (GWh/ktoe)	1.82	0.04	5.33	11.63	11.63	0.00

Source: Calculations using IEA (2017a)

Table 5.10.4. Projected growth rates for Vietnam

	Average Annual Growth Rates
GDP (2023–2030)	6.09%
TPES per GDP (2016–2030)	-0.04%
Population (2016–2030)	0.94%

Source: Calculations using IEA (2017a), IMF (2017), and UN (2017)

6 Economy-wide Analyses for Indonesia and Vietnam

Main Takeaways

- Policies to reduce GHG emissions require re-allocation of investment to low-carbon options.
- Output of energy-intensive sectors of the economy is substantially affected by climate policy.
- GHG emission mitigation efforts should be based on economy-wide coverage rather than on selected sectors of the economy.
- NDC goals for Indonesia and Vietnam are achievable at a manageable cost. For an economy-wide policy, the GDP cost in Indonesia and Vietnam is only 0.03% and 0.008%, respectively, relative to GDP in the BAU (No Policy) scenario in 2030.
- Carbon prices to achieve emission reduction targets vary with a policy design. In 2030 in Vietnam they are in the range of \$2–16/tCO_2e to meet the unconditional NDC target and in the range of \$44–120/tCO_2e to meet the conditional target. In 2030 in Indonesia they are in the range of \$18–54/tCO_2e to meet the unconditional target and in the range of \$27–82/tCO_2e to meet the conditional target.
- Digitalization offers a potential to reduce costs of meeting NDC targets.

In this section, we develop and deploy bespoke applied general equilibrium (AGE) models of Indonesia and Vietnam. These models provide (1) an alternative method to project 'business as usual' GHG emissions, and (2) a tool to numerically estimate the economic, energy and emissions impacts of policy and technology options to meet emission reduction targets.

6.1 Modeling Framework

AGE models combine general equilibrium theory with realistic economic data to solve numerically for the levels of supply, demand and price that support equilibrium across all markets (Sue Wing, 2004). These models represent economies as a series of interconnected sectors, include a detailed representation of energy production, and link production (and consumption) to GHG emissions. AGE models have been extensively used to for quantitative climate policy analysis—see, for example Caron *et al.* (2015), Vandyck *et al.* (2016), Singh *et al.* (2018), Winchester *et al.* (2010), and Winchester and Reilly (2018). A key advantage of AGE model relative to energy system models such as the MARKet Allocation (MARKAL) and the The Integrated MARKAL-EFOM System (TIMES) models (Loulou *et al.*, 2004) is that AGE models consider economic activity and GHG emissions in all sectors. This feature is salient for ASEAN nations as agriculture accounts for a significant proportion of GHG emissions in most member countries, including Indonesia and Vietnam.

The sectoral aggregation of the model used for the economy-wide analyses is outlined in Table 6.1. The model represents 10 sectors related to energy extraction, production and distribution, including six electricity generation technologies (coal, gas, oil/diesel, hydro, wind & solar, and other renewables). Due to the significant amounts of methane emissions from rice growing in both Indonesia and Vietnam, paddy rice is separated from other agriculture. The model also represents five energy-intensive manufacturing sectors (chemical, rubber, and plastic products; non-metallic minerals; iron and steel; non-ferrous metals; and fabricated metal products)[1] and three other manufacturing sectors (food manufacturing; motor vehicles and parts; and other manufacturing). Other sectors represented in the model include other mining, transportation, and services. Additional information about the model used for the economy-wide analyses is provided in Appendix E.

1 For Vietnam, as production of iron and steel, non-ferrous metals, and fabricated metal products are small, these sectors are aggregated to an 'Other energy-intensive' sector in the analysis for this country.

Table 6.1. Sectoral aggregation

Energy extraction, production & distribution		Other sectors	
cru	Crude oil extraction	pdr	Paddy rice
oil	Refined oil products	agr	Other agriculture
col	Coal extraction	omn	Other mining
gas	Natural gas extraction and distribution	crp	Chemical, rubber & plastic products
ecoa	Coal electricity	nmm	Non-metallic minerals
egas	Gas electricity	i_s	Iron and steel*
eoil	Oil electricity	nfm	Non-ferrous metals*
ehyd	Hydro electricity	fmp	Fabricated metal products*
ews	Wind & solar electricity†	fod	Food processing
eoth	Other renewable electricity†	mvh	Motor vehicles and parts
tnd	Electricity transmission and distribution	omf	Other manufacturing
		trn	Transportation
		ser	Services

† Included in 'Other renewables electricity' for Indonesia. '* Aggregated to 'Other energy-intensive industry' for Vietnam.

6.2 Policy and Technology Scenarios

We implement seven scenarios for each country, which are summarized in Table 6.2. The first scenario, BAU, creates projections for economic, energy and GHG emission outcomes in each country in 2030 under a hypothetical 'no climate policy' or 'business as usual' (BAU) case. Key inputs for each BAU simulation include, GDP growth, autonomous energy efficiency improvements, and autonomous improvements in non-combustion GHG intensities.

The BAU scenario imposes specified 2030 GDP projections by endogenously determining economy-wide technology improvements in the model. As in the Gap Analysis, the cumulative annual average growth rate imposed out to 2030 in the BAU scenario is equal to 5.30% for Indonesia, and 6.34% for Vietnam. In the remaining scenarios, economy-wide improvements in technology equal those in the BAU scenario and GDP is endogenous. Guided by historical trends and assumptions made in the MIT EPPA model (Paltsev *et al.*, 2005; Chen *et al.*, 2016), the BAU scenario also imposes autonomous energy efficiency improvements of 1.5% per year, and autonomous improvements in non-combustion GHG intensities of 1.5% per year. All other outcomes—such as electricity generation by technology, GHG emissions, and sectoral output—are endogenous in the BAU scenario (and other scenarios) and are driven by technologies, consumer preferences, policy incentives and resources constraints.

Table 6.2. Scenarios

Name	Description
Benchmark	Selected economy as represented by the benchmark data in 2011
BAU	Selected economy in 2030 under 'Business as usual' (no climate policies)
UNCON-ALL	Unconditional (UNCON) emissions target using an ETS on ALL sectors
UNCON-SEL	Unconditional emissions target using an ETS on selected (SEL) sectors
CON-ALL	Conditional (CON) emissions target using an ETS on all sectors
CON-SEL	Conditional emissions target using an ETS on selected sectors
CON-ALL-DIG	CON-ALL with increased adoption of digitalization (DIG)
CON-SEL-DIG	CON-SEL with increased adoption of digitalization

The remaining six scenarios simulate an emissions trading system (ETS) to meet NDC emission targets. Countries may chose alternative policies to meet NDC targets. We impose an ETS in all scenarios as this is widely acknowledged as a 'first best' (i.e., least-cost) policy and focus our analysis on the important impacts of (1) the level of ambition for reducing emission (unconditional vs. conditional targets), (2) the sectoral scope of the policy, and (3) the adoption of alternative technologies. This is achieved by designing scenarios that differ with respect to (1) the economy-wide emissions target, (2) the sectoral coverage of the ETS, and (3) the adoption of digitalization in electricity generation. Simulated economy-wide emissions targets include those consistent with unconditional (UNCON) and conditional (CON) NDC pledges. Proportional reduction in emissions consistent with conditional and targets in 2030 relative to those in BAU are displayed in Table 6.3. These targets exclude emissions from LULUCF.

The unconditional and conditional emissions reductions are imposed using an ETS that covers either all (ALL) sectors or selected (SEL) sectors. In scenarios that impose an ETS on selected sectors, electricity sectors, energy-intensive industries, and refined oil products are covered by the ETS, and there are no regulations on emissions from other sectors.

Table 6.3. Economy-wide emissions reductions relative to 2030 BAU

	Unconditional	Conditional
Indonesia	16%	20%
Vietnam	8%	25%

The UNCON-ALL scenario uses an ETS to meet the target country's unconditional emissions target using an ETS on ALL sectors, while the UNCON-SEL simulation meets the same emissions target using an ETS on selected sectors. Similarly, the CON-ALL and CON-SEL scenarios meet conditional emission targets using ETSs covering, respectively, all and selected sectors.

The final two scenarios, CON-ALL-DIG and CON-SEL-DIG, impose the conditional emissions targets under the assumption that, relative to BAU, increased adoption of digitalization (DIG), increases energy conversion efficiency in fossil power generation by 5%; and (for Vietnam only) increases the penetration of other renewable electricity by 20%.[2] Our digitalization-induced efficiency improvements in fossil generation are informed by estimates by Annunziata and Bell (2015). For renewables, (GE, 2018b) notes that GE's Digital Wind Farm software and hardware suite can improve the energy output of a wind farm by up to 20% over the course of its life, and Annunziata and Bell (2015) estimate that digitalization can increase the adoption of renewables by optimizing generation portfolios.

2 Both the increase in energy conversion efficiency and the penetration of other renewables are at constant prices (i.e., before the model solves for the new set of equilibrium prices), so price changes when the model solves for a new equilibrium induce simulated increases that differ from the exogenously-imposed increases.

6.3 Results for Indonesia

Modeling Results

- Indonesia can reduce emissions at a lower cost by incenting emission reductions in as many sectors as possible. For example, meeting Indonesia's unconditional NDC target using an economy-wide ETS results in a carbon price of \$17.5/tCO_2e and reduces GDP by 0.03%, while the same reduction in emissions using an ETS that just covers the electricity and energy-intensive industries requires a carbon price of \$53.5/tCO_2e and reduces GDP by 0.14%.
- Meeting Indonesia's conditional emissions reduction requires a higher carbon price and has a larger GDP cost than its unconditional target. For example, when there is an economy-wide ETS, deeper emission cuts associated with the conditional target require a carbon price of \$28.9/tCO_2e and a decline in GDP of 0.07% (compared to, respectively, \$17.5/tCO_2e and 0.03% for the unconditional target).
- Increased adoption of digitalization in electricity generation lowers the cost of meeting emissions reduction targets. For example, when an economy-wide ETS is used to meet Indonesia's conditional target, digitalization reduces the reduction in GDP cost from 0.07% to 0.01%.

A summary of results for Indonesia for each scenario is reported in Table 6.4, with additional results in Figures 6.1 (GHG emissions), 6.2 (electricity generation), 6.3 (primary energy), and Table 6.5 (sectoral output changes for selected scenarios).[3] In the BAU scenario, the imposed level of GDP in 2030 is \$2,277.0 billion (in 2011 dollars), an increase of 171.6% relative to 2011. Total GHG emissions in 2030 are 1,146.4 MtCO_2e, a 93.6% increase relative to 2011. The GHG intensity of GDP, therefore, decreases by 28.7% between 2011 and 2030. Electricity generation and primary energy use in 2030 are, respectively, 636.9 TWh and 271.5 Mtoe.

In the UNCON-ALL scenario, a carbon price of \$17.5/tCO_2e (applied to all gases in all sectors) is required to reduce 2030 economy emissions by 16% relative to BAU. By increasing the price of electricity, the carbon price causes a 7.7% decrease in total electricity production, with a 17.2% decrease in electricity from coal (the most CO_2 intensive electricity technology) and small increases in electricity from gas and other renewables, which have lower CO_2 intensities (Figure 6.2). Total primary energy falls by 6.7% with primary energy from coal falling by 17.5% and smaller proportional reductions in primary energy from oil and gas (Figure 6.3). Additional costs due to the carbon price reduces GDP by 0.03% relative to the BAU level.

When the unconditional target is met using an ETS on selected energy and energy-intensive sectors, UNCON-SEL, the required carbon price increases by a factor three, to \$53.5/tCO_2e. This is because: (1) under BAU conditions, emissions from selected sectors account for only 50.4% of total emissions, and (2) there is leakage of emissions from covered sectors to uncovered sectors; that is, emissions from sectors not covered by the ETS (other sectors) increase from, in MtCO_2e, 568.2 under BAU conditions to 571.0. Consequently, a 32.2% reduction in emissions from selected sectors is required meet the economy-wide emissions reduction target (compared to 15.3% in the UNCON-ALL scenario). Ultimately, as sectoral marginal abatement costs increase with the level of emissions abated, a higher carbon is needed to induce selected sectors to undertake larger emissions reduction.

The higher carbon price in the UNCON-SEL scenario leads to larger changes in electricity outcomes in the UNCON-ALL. Total electricity generation decreases by 19.1% relative to BAU, with generation from coal decreasing by 42.5% and generation from gas and other renewables increasing by, respectively, 9.6% and 9.7%. There is also a larger reduction in primary energy

3 Results displayed in Figures 6.1–6.3 are presented in table for in Appendix E.

in the UNCON-SEL scenario than when the ETS covers all sectors, with primary energy from coal falling by 41.0%. As transportation is not covered by the ETS in the UNCON-SEL scenario, primary energy from oil increases relative to the UNCON-ALL scenario.

Table 6.4. Indonesia: Summary results in 2030

	BAU	UNCON-ALL	UNCON-SEL	CON-ALL	CON-SEL	CON-ALL-DIG	CON-SEL-DIG
GDP billion 2011$	2,278.0	2,277.3	2,274.8	2,276.3	2,271.9	2,277.9	2,273.6
GDP % change	-	-0.03%	-0.14%	-0.07%	-0.27%	-0.01%	-0.19%
CO_2 price 2011$/t$CO_2$e	-	17.5	53.5	28.9	81.7	27.4	78.8
GHG emissions MtCO_2e							
Selected sectors	578.2	489.6	392.0	453.1	344.3	451.5	343.8
Other sectors	568.2	473.4	571.0	464.0	572.7	465.6	573.3
All sectors	1,146.4	962.9	962.9	917.1	917.1	917.1	917.1
Elec. generation TWh	636.9	588.0	515.1	560.9	478.8	575.5	490.8
Primary energy Mtoe*	271.5	253.3	231.5	243.2	219.7	242.8	219.5

Note: * Primary energy for electricity from hydro and other renewables follows the physical energy content method. That is, the primary energy equivalent from these sources is equal to the energy content of electricity generated.

Table 6.5. Indonesia: Output changes in 2030 relative to BAU, 2011$ and %

	CON-ALL		CON-SEL		CON-SEL-DIG	
	$, m	%	$, m	%	$, m	%
Crude oil	0.016	0.1%	0.010	0.1%	0.011	0.1%
Refined oil products	-1.031	-1.9%	-0.599	-1.1%	-0.638	-1.1%
Coal extraction	0.154	0.2%	-0.684	-0.7%	-0.677	-0.7%
Natural gas extraction & dist.	0.070	0.2%	0.124	0.3%	0.131	0.4%
Coal electricity	-2.900	-26.7%	-5.976	-55.0%	-5.718	-52.6%
Gas electricity	0.553	6.3%	1.045	12.0%	1.350	15.5%
Oil electricity	0.000	0.0%	0.000	0.0%	0.000	0.0%
Hydro electricity	0.000	0.0%	0.000	0.0%	0.000	0.0%
Other renewable electricity	0.110	6.1%	0.224	12.4%	0.213	11.8%
Electricity transmission & distrib.	-0.589	-9.1%	-1.382	-21.3%	-1.233	-19.0%
Paddy rice	-0.011	0.0%	0.001	0.0%	0.001	0.0%
Other agriculture	-0.029	0.0%	-0.005	0.0%	-0.005	0.0%
Other mining	-0.623	-0.4%	-0.883	-0.5%	-0.773	-0.4%
Chemical, rubber & plastic prod.	-4.249	-0.9%	-10.052	-2.2%	-9.395	-2.1%
Non-metallic minerals	-0.839	-1.1%	-2.088	-2.8%	-1.966	-2.6%
Iron and steel	-2.136	-3.0%	-5.365	-7.6%	-4.900	-6.9%
Non-ferrous metals	-0.975	-0.7%	-1.976	-1.5%	-1.728	-1.3%
Fabricated metal products	-0.992	-0.5%	-2.047	-1.1%	-1.804	-0.9%
Food processing	0.064	0.0%	0.130	0.1%	0.138	0.1%
Motor vehicles and parts	-2.098	-1.7%	-2.523	-2.0%	-2.305	-1.9%
Other manufacturing	-2.985	-0.5%	-2.386	-0.4%	-2.325	-0.4%
Transportation	-3.813	-1.2%	-2.086	-0.7%	-1.845	-0.6%
Services	-5.135	-0.2%	-11.463	-0.5%	-9.477	-0.4%

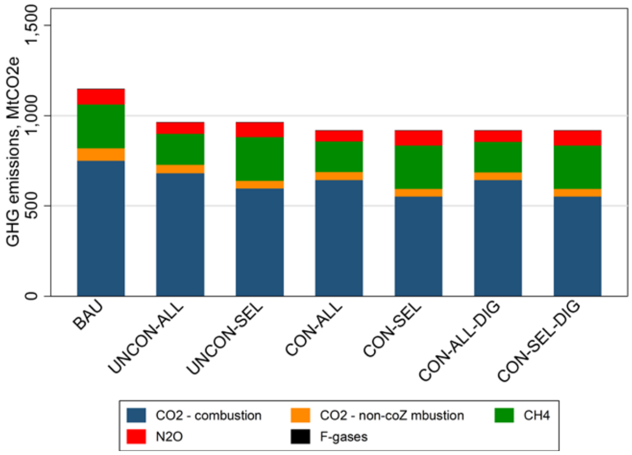

Figure 6.1. Indonesia: GHG emissions in 2030, $MtCO_2e$

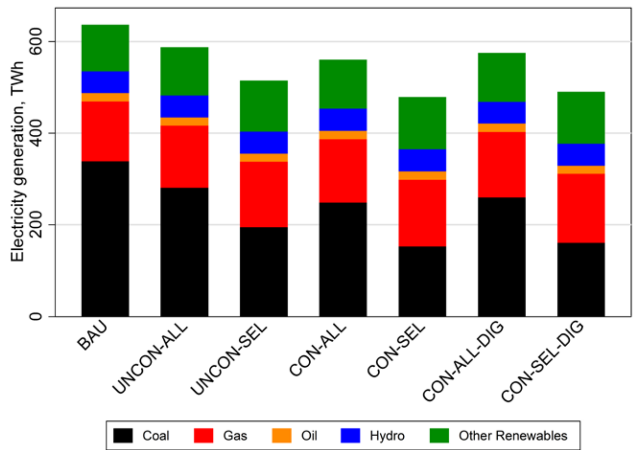

Figure 6.2. Indonesia: Electricity generation in 2030, TWh

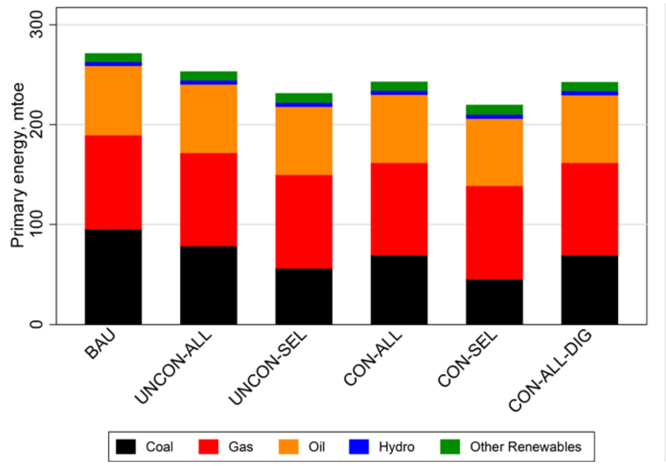

Figure 6.3. Indonesia: Primary energy in 2030, Mtoe

Note: * Primary energy from nuclear is based on the amount of heat generated in reactors assuming a 33% conversion efficiency. For wind, solar and hydro, the primary energy equivalent is the physical energy content of electricity generated.

The reduction in GDP relative to BAU when the ETS covers selected sectors (0.14%) increases by a factor of 4.5 relative to when all sectors are included (0.03%). The partial coverage of the ETS, relative when all sectors are included in the ETS, leads to increased production by uncovered sectors and decreased output in covered sectors (Table 6.5). Ultimately these production shifts change the emissions profile of Indonesia (Figure 6.1), with a higher proportion of emissions of non-CO_2 GHGs, which are mainly from sectors not covered by the ETS (e.g., agriculture).

Meeting the conditional target of reducing economy-wide emissions by 20% in the CON-ALL and CON-SEL scenarios leads to a higher carbon prices and GDP costs relative to the corresponding scenarios with unconditional (less stringent) emission reduction targets. The impacts of deeper emission cuts are largest in the CON-SEL scenario. In this simulation, the carbon price is 81.7/tCO_2e and GDP decreases by 0.27% relative to BAU. Total electricity generation falls by 24.8%, with a 55.0% decrease in coal power, and increases in electricity from gas and other renewables of, respectively, 12.0% and 12.4%.

Increased adoption of digitalization in the electricity sector is considered in the final two scenarios. The impact of increased digitalization in the electricity sector can be evaluated by comparing results from the CON-ALL-DIG and CON-SEL-DIG to, respectively, the CON-ALL and CON-SEL scenarios. The impact of increased digitalization adoption is largest when the ETS only covers selected energy and energy intensive sectors, as higher carbon prices in these scenarios relative to when the all sectors are included results in greater benefits from digitalization-induced improvements in fossil-fuel electricity generation. Comparing the results for the CON-SEL-DIG scenario to those for the CON-SEL reveals that increased digitalization lowers the cost of meeting the emissions constraint (i.e., GDP is $1.8 billion higher in the CON-SEL-DIG scenario than in the CON-SEL scenario), and lowers the carbon price (from $81.7 to $78.8).[4]

Electricity generation is also higher when there is increased digitalization, as it lowers the CO_2 intensity of fossil fuel generation. When the ETS only covers selected sectors, more digitalization increases total electricity generation, in TWh, from 478.8 to 490.8, with increases in electricity from coal and gas. These results indicate that, if it is cost effective, increased digitalization could help Indonesia meet the dual goals of expanding electricity access while curbing GHG emissions.

6.3.1 Policy Recommendations for Indonesia

Main Takeaways

- Further strengthening of the existing policy portfolio, including more ambitious targets and coordination of policies in the power sector with policies in other sectors.
- Going forward, emissions growth will shift from rainforest and peatland loss to the energy sectors, where robust economic growth has resulted in a steep increase in energy demand.
- Indonesia's institutional and regulatory framework is favorable for a transition towards a secure and sustainable energy supply, and its untapped renewable energy potential presents a unique opportunity to accelerate the shift to renewable energy sources in electricity generation, heating, and transport.
- Indonesia should adopt more ambitious targets for renewable energy deployment in its national energy strategy. Accelerating the shift to renewable energy sources will mobilize additional benefits, reducing pollution and associated health impacts.
- Carbon pricing may be used as a source of much-needed revenue for public budgets.
- Indonesia should continue current efforts to reform fossil fuel subsidies, as further subsidy reductions will likewise reduce the strain on public budgets. Combined with carbon pricing revenue, this will allow Indonesia to invest greater financial resources towards innovation and infrastructure.

Based on our gap analysis in Section 5.3 and our detailed economic analysis in Section 6, we recommend further strengthening of the existing policy portfolio, including more ambitious targets for low-carbon generation and coordination of policies in power sector with policies in the other sectors of the Indonesian economy.

Currently, emissions from rainforest and peatland loss still dominate the country's emissions profile. Going forward, however, emissions growth will shift to the energy sectors, where robust economic growth has also resulted in a steep increase in energy demand, seeing electricity demand, for instance, almost double over the last decade.

Intended expansion of coal-fired electricity generation, in particular, will pose a substantial challenge for achievement of Indonesia's pledged mitigation targets, yet it aligns with the strategic objective of achieving greater energy security: with its abundant hard and brown coal reserves, Indonesia is currently a major coal exporter (Mersmann *et al.*, 2017).

4 As efficiency improvements in power generation have two opposing impacts on carbon price, the small (aggregate) change in carbon prices due to digitalization is not surprising. On one hand, increased conversion efficiency for electricity generation lowers the carbon price required to reduce emissions. On the other hand, the efficiency improvements increase the carbon price by (1) reducing costs for electricity-intensive industries, which leads to increased electricity demand; and (2) reducing the price of fossil fuels, which leads to more use of these fuels in other sectors.

For future policy design, this poses a twofold challenge. To be effective at curbing emissions, an instrument portfolio has to both address the substantial emissions from land use, land use change and forestry, while shifting the further expansion of energy production towards natural gas and, more effectively, Indonesia's abundant domestic renewable resources.

Timing is also a critical factor: as Indonesia progresses with its planned expansion of electricity generation capacity, it faces a considerable risk of long-term carbon lock-in. As it implements the Electricity Supply Business Plan for 2016–2025 (RUPTL), which anticipates the addition of 80 GW in generating capacity over the course of a decade, any new fossil-fueled generation capacity will continue to emit over the considerable useful economic life of these assets.

Already, the country has implemented a favorable institutional and regulatory framework to increase its future climate policy ambition and ensure a transition towards a secure and sustainable energy supply. Addressing climate change has been declared a political priority at the highest levels of government, and the current President has repeatedly affirmed his commitment to mitigating emissions and protecting Indonesia's rainforests.

A newly formed Directorate General of Climate Change, operating under the auspices of the Ministry of Environment and Forestry, can work alongside the powerful Ministry of National Development Planning (BAPPENAS) to implement the National Action Plan for Greenhouse Gas Reduction (RAN-GRK), a presidential decree of 2011 which sets out a cross-sectoral framework for Indonesia's climate strategy (Nachmany *et al.*, 2015).

Mitigation actions in seven key areas are set out in the RAN-GRK: sustainable peat land management; reducing the deforestation and land degradation rate; developing carbon sequestration projects in forestry and agriculture; promoting energy efficiency; developing alternative and renewable energy sources; reducing solid and liquid waste; and shifting to low-emission transportation mode (BAPPENAS, 2011).

A National Energy Policy (KEN) sets out targets for the future development of Indonesia's energy mix, and is complemented by the Electricity Supply Business Plan 2016–2025 (RUPTL) mentioned earlier. Under these broad planning tools, Indonesia aims to expand its share of renewable energy to 23% by 2025 (ICED 2016). National energy policy is further operationalized by Law 30/2007 Regarding Energy as well as the National Energy Conservation Master Plan (RIKEN), both of which regulate energy demand and set energy efficiency targets, including a national target to decrease energy intensity by 1% annually until 2025. Different feed-in tariffs and tax incentives support geothermal, solar, waste-to-energy, hydropower, and bioenergy.

In the area of land use, land use change, and deforestation, cooperation with international donors has resulted in a temporary moratorium on new forestry licenses and peatland development. A "One Map Initiative" aimed at developing a unified forestry mapping system has the potential to greatly increase transparency on emissions from deforestation. In the transportation sector, whose emissions are likewise growing at a rapid pace, several pilot and demonstration projects seek to expand use of public transportation and improve urban transportation infrastructure (Mersmann *et al.*, 2017).

As Indonesia considers options to further strengthen its existing policy portfolio, it has a unique opportunity to accelerate the shift from continued growth of fossil fuels in electricity generation, heating, and transport to renewable energy sources. While Indonesia enjoys abundant domestic reserves of hard and brown coal, it is also richly endowed with untapped renewable energy potential, especially in biomass, geothermal, hydropower, solar, and tidal energy (IRENA, 2017). Not only will substitution of fossil resources with renewable energy be essential to achieve mitigation objectives, it will also mobilize important additional benefits, such as reduced air and water pollution as well as associated health impacts.

This should be translated into more ambitious targets for renewable energy deployment in Indonesia's national energy strategy. Rapidly falling technology costs make a much more aggressive expansion trajectory for renewable energy economically viable. A transition away from the established fossil fuel sector will face resistance and necessitate careful planning to avoid social hardship, but opportunities for strong growth, employment and innovation also exist along the renewable energy supply chain. Overall, net benefits of a transition will outweigh costs (IRENA, 2017).

But accelerating growth in renewable energy use will require coordinated action along multiple levels. Renewable energy auctions are a proven instrument to cost-effectively scale up growth of renewable energy while retaining control over the pace and cost of the transition (see Section 7.1.2). Increased reliance on renewable energy auctions needs to be complemented by forward-looking infrastructure planning to ensure grid integration of new and variable generation capacities, including in remote areas with small, isolated grids. International cooperation and policy learning can help build technical capacity and inform future reforms of Indonesia's electricity market with a view to better managing an evolving electricity mix (see Section 4.1.4).

Emissions are also rapidly growing in the transport and residential sectors. Carefully managed to minimize land use impacts, expanded use of natural gas and biofuels can play a considerable role in reducing the emissions intensity of these sectors. Continued use of targeted energy efficiency measures offer a useful way to curb emissions growth, but can suffer from low cost-effectiveness and have unintended effects (see Section 4.1.1 and 4.1.3). Over time, Indonesia should therefore consider instituting a price on carbon to leverage this policy's ability to scale up abatement at least cost across all sectors, create a more even playing field between carbon-intensive and renewable technologies, and potentially leverage carbon finance from third countries through offset projects or international linkage of carbon pricing policies. Indonesia already has a good track record of international carbon market participation under the Clean Development Mechanism (CDM) of the Kyoto Protocol and, more recently, the bilateral Joint Crediting Mechanism (JCM) with Japan.

Rather than relying on public expenditures, as many current measures do, carbon pricing could also be a source of much-needed revenue for public budgets. It is also vitally important that Indonesia continue initial efforts under the current administration to reform fossil fuel subsidies, which continue to bind a significant share of the public budget (ADB, 2015a). Although a weakening currency and rising fossil fuel prices make it harder to sustain the recent pace of reform, further subsidy reductions will likewise reduce the strain on public budgets. Combined with carbon pricing revenue, this will allow Indonesia to allocate greater financial resources to strategic investment in innovation and infrastructure development, which will be key for further growth of renewable energy in electricity generation, but also, for the longer-term, electrification of transport.

More generally, institutional and regulatory challenges, including fragmented governance structures involving a large number of government actors, have been identified as barriers to effective translation of national commitments to the regional and local level (Resosudarmo *et al.*, 2013). While the creation of the Directorate General of Climate Change marks a useful first step, further integration and mainstreaming of climate policy priorities across all levels of government is recommended. Clientelism and vested interests of powerful economic stakeholders have also been identified as obstacles to sound governance, and may deter policy reform as well as domestic and foreign investment in renewable energy source (Di Gregorio *et al.*, 2017).

6.4 Results for Vietnam

Modeling Results

- Vietnam can reduce emissions at a lower cost by incenting emissions reduction in as many sectors as possible. For example, meeting Vietnam's unconditional NDC target using an economy-wide ETS results in a carbon price of \$2.2/tCO_2e and reduces GDP by 0.008%%, while the same reduction in emissions using an ETS that just covers the electricity and energy-intensive industries requires a carbon price of \$16.3/tCO_2e and reduces GDP by 0.07%.
- Meeting Vietnam's conditional emissions reduction requires a higher carbon price and has a larger GDP cost than its unconditional target. For example, when there is an economy-wide ETS, deeper emission cuts associated with the conditional target require a carbon price of \$44.7/tCO_2e and a decline in GDP of 0.54% (compared to, respectively, \$2.2/tCO_2e and 0.008% for the unconditional target).
- Increased adoption of digitalization in electricity lowers the cost of meeting emissions reduction targets. For example, when an economy-wide ETS is used to meet Vietnam's conditional target, digitalization reduces the reduction in GDP cost from 0.54% to 0.25%.

A summary of results for Vietnam for each scenario is reported in Table 6.6 with additional results in Figure 6.4 (GHG emissions), 6.5 (electricity generation), 6.6 (primary energy), and Table 6.7 (sectoral output changes for selected scenarios).[5] In the BAU scenario, GDP in 2030 is \$523.4 billion (in 2011 dollars), an increase of 227.3% relative to 2011. Total GHG emissions in 2030 are 631.4 MtCO_2e, a 190.9% increase relative to 2011. The GHG intensity of GDP, therefore, decreases by 19.0% between 2011 and 2030. Electricity generation and primary energy use in 2030 are, respectively, 401.4 TWh and 147.3 Mtoe.

In the UNCON-ALL scenario, a carbon price of \$2.2/tCO_2e, applied to all gases in all sectors, is required to reduce 2030 economy emissions by 8% relative to BAU. The relatively low carbon price causes small reductions in electricity generation (Figure 6.5) and primary energy use (Figure 6.6). Meeting the emissions constraint reduces GDP by 0.008%.

In the UNCON-SEL scenario, reducing emissions by 8% using an ETS on selected energy and energy-intensive sectors requires a carbon price of \$16/tCO_2e. The ETS in this scenario covers 56.4% of total emissions under BAU conditions. There is also leakage of emissions to sectors not covered by the ETS (other sectors) of 7.2 MtCO_2e (282.2–275.0) in the UNCON-SEL scenario. As a result, sectors covered by the ETS (selected sectors) reduce their emissions by 16.2% to meet the 8% economy-wide emissions reduction target. As for Indonesia, the higher carbon price in the UNCON-SEL scenario relative to the UNCON-ALL scenario is due to sectoral marginal abatement costs increasing as the level of abatement increases.

The carbon price in the UNCON-SEL scenario reduces total electricity generation by 4.3% relative to BAU, with coal electricity generation decreasing by 12.4%. Changes in primary energy follow a similar pattern to those for electricity (Figure 6.5). Relative to BAU, total primary energy decreases by 3.9% and that from coal falls by 8.2%. Meeting the unconditional emissions target with a selected-sectors ETS reduces GDP by 0.07%. There is also an increase in the proportion of non-CO_2 emissions in total emissions in the selected-sectors ETS simulations (Figure 6.4). As for Indonesia, this largely driven by increased production from uncovered sectors (e.g., agriculture) and decreased production from covered sectors (Table 6.7).

5 Results displayed in Figures 6.4–6.6 are presented in table for in Appendix E.

Table 6.6. Vietnam: Summary results in 2030

	BAU	UNCON-ALL	UNCON-SEL	CON-ALL	CON-SEL	CON-ALL-DIG	CON-SEL-DIG
GDP billion 2011$	523.4	523.3	523.0	520.5	514.2	522.1	515.9
GDP % change	-	-0.008%	-0.07%	-0.54%	-1.76%	-0.25%	-1.43%
CO_2 price 2011$/t$CO_2$e	-	2.2	16.3	44.7	120.1	44.2	115.4
GHG emissions MtCO_2e							
Selected sectors	356.4	332.3	298.6	253.1	160.7	252.5	160.3
Other sectors	275.0	248.5	282.2	220.5	312.9	221.0	313.3
All sectors	631.4	580.9	580.9	473.5	473.5	473.5	473.5
Elec. generation TWh	401.4	399.8	384.1	359.7	290.8	368.4	296.6
Primary energy Mtoe*	148.0	147.1	142.3	125.6	115.7	126.2	116.1

Note: * Primary energy for electricity from hydro and other renewables follows the physical energy content method. That is, the primary energy equivalent from these sources is equal to the energy content of electricity generated.

Table 6.7. Vietnam: Output changes in 2030 relative to BAU, 2011$ and %

	CON-ALL		CON-SEL		CON-SEL-DIG	
	$, m	%	$, m	%	$, m	%
Crude oil	0.105	0.5%	0.088	0.4%	0.086	0.4%
Refined oil products	-0.417	-2.5%	-0.231	-1.4%	-0.239	-1.4%
Coal extraction	-0.413	-3.1%	-0.841	-6.3%	-0.831	-6.2%
Natural gas extraction & dist.	-0.001	0.0%	-1.112	-17.5%	-1.269	-20.0%
Coal electricity	-4.151	-30.5%	-9.281	-68.1%	-9.369	-68.8%
Gas electricity	-0.421	-2.9%	-2.907	-20.3%	-2.881	-20.2%
Oil electricity	0.000	0.0%	0.000	0.0%	0.000	0.0%
Hydro electricity	0.000	0.0%	0.000	0.0%	0.000	0.0%
Wind & solar electricity	0.257	4.0%	0.847	13.2%	2.138	33.3%
Other renewable electricity	0.050	1.7%	0.157	5.4%	0.137	4.7%
Electricity transmission & distrib.	-1.032	-8.0%	-2.878	-22.3%	-2.559	-19.9%
Paddy rice	-0.027	-0.2%	0.001	0.0%	0.001	0.0%
Other agriculture	-0.020	-0.1%	0.029	0.1%	0.021	0.1%
Other mining	-0.292	-3.3%	-0.622	-7.1%	-0.561	-6.4%
Chemical, rubber & plastic prod.	-0.104	-0.1%	-5.636	-7.0%	-4.784	-6.0%
Non-metallic minerals	-2.861	-7.3%	-6.704	-17.2%	-6.437	-16.5%
Other energy-intensive industry	-12.843	-27.3%	-30.111	-64.0%	-28.296	-60.2%
Food processing	-0.088	-0.2%	-0.037	-0.1%	-0.031	-0.1%
Motor vehicles and parts	0.326	2.6%	0.814	6.4%	0.749	5.9%
Other manufacturing	3.298	0.8%	18.561	4.7%	18.894	4.8%
Transportation	-2.030	-8.5%	0.029	0.1%	0.093	0.4%
Services	-1.543	-0.5%	-3.321	-1.1%	-2.635	-0.8%

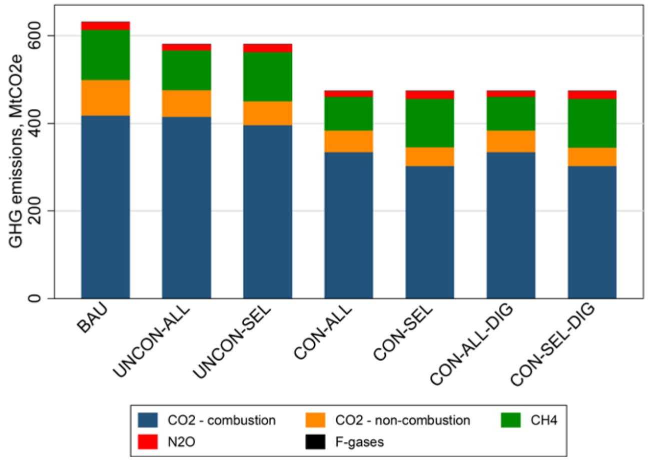

Figure 6.4. Vietnam: GHG emissions in 2030, $MtCO_2e$

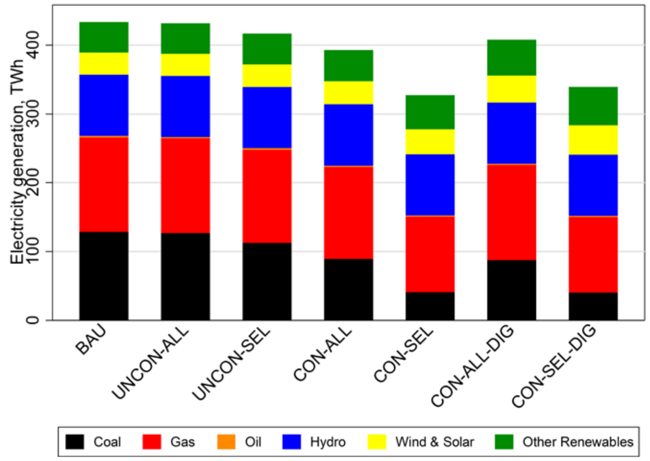

Figure 6.5. Vietnam: Electricity generation in 2030, TWh

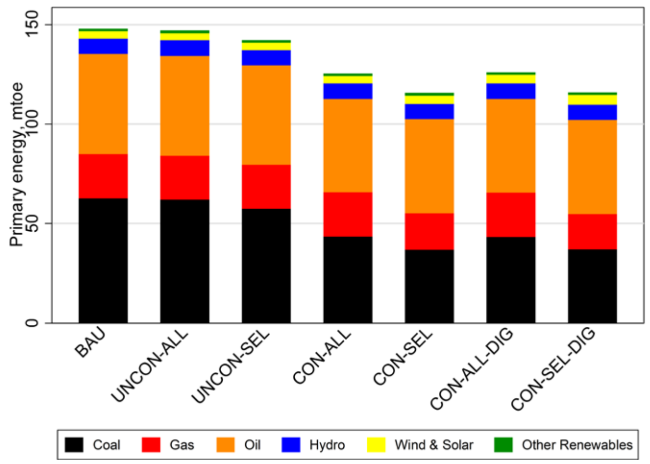

Figure 6.6. Vietnam: Primary energy in 2030, Mtoe

Note: * Primary energy from nuclear is based on the amount of heat generated in reactors assuming a 33% conversion efficiency. For wind, solar and hydro, the primary energy equivalent is the physical energy content of electricity generated.

Imposing the (more ambitious) conditional target of reducing economy-wide emissions by 25% in the CON-ALL and CON-SEL scenarios leads to higher carbon prices and GDP costs relative to simulating the unconditional emission targets. For example, meeting the (more stringent) conditional target instead of the (less stringent) unconditional target using an ETS covering selected sectors increases the carbon price from \$16/tCO_2e (UNCON-SEL) to \$120/tCO_2e (CON-SEL), and increases the reduction in GDP from 0.07% of the BAU level to 1.76% of the BAU level. In the CON-SEL scenario, relative to BAU, total electricity production falls by 27.6%, with a 68.1% decrease in coal power generation, a 20.3% decrease in electricity from gas, and a 13.2% increase in electricity from wind and solar. These numbers highlight the additional costs of deeper emissions cuts in Indonesia.

Increased digitalization in power generation increases total generation by reducing the price of electricity. Therefore, if it is cost effective, this method could help Vietnam decrease GHG emissions while increasing electricity access.

In the CON-ALL-DIG and CON-SEL-DIG scenarios, as is the case for Indonesia, increased adoption of digitalization in the electricity sector reduces the GDP costs of meeting the emissions constraint. For example, when reducing emissions using an all-sectors ETS, increased digitalization reduces the GDP cost from 0.54% of BAU GDP (CON-ALL) to 0.25% (CAN-ALL-DIG); that is, increased digitalization in power generation increases GDP by $1.6 billion ($522.1–$520.5). Increased digitalization also lowers the carbon prices in the CON-ALL and CON-SEL scenarios.

More digitalization in power generation, by reducing the price of electricity, also increases total electricity generation. These results indicate that, if it is cost effective, increased digitalization could help Vietnam to decrease GHG emissions while also increasing electricity access.

6.4.1 Policy Recommendations for Vietnam

Main Takeaways

- Together, low prices for electricity and coal, modest and unevenly-enforced incentives, and barriers to private-sector market entry dampen prospects for energy efficiency improvements and rapid growth in renewable energy generation.
- Strengthening and enforcement of existing energy policies, continued energy price reform and power sector restructuring, and, prospectively, introduction of a carbon price are all suited to advance decarbonization of Vietnam's power sector.
- Policy should focus on ensuring that new generation capacity is based on renewables and natural gas rather than coal and, in the short term, curbing energy demand growth as a way to buy time for fuel switching.
- Ongoing power sector reforms may spur transition to a competitive electricity market, with prices determined by market dynamics, potentially enabling scaled-up investment in clean energy technologies such as renewable energy sources, natural gas, and energy efficiency.
- For Vietnam's announced carbon price to be effective, continued equitization of state-owned enterprises and deregulation of electricity tariffs will be critical to foster responsiveness to market signals.
- Ultimately, a carbon price will also help channel private sector finance to low-carbon investments, helping overcome another major barrier for mitigation efforts faced in Vietnam.

Our policy recommendations for Vietnam focus on bringing down its energy intensity, which is the highest among major East Asian economies (Audinet *et al.*, 2016), and shifting future growth in electricity generation capacity to renewables and natural gas. Strengthening and better enforcement of existing policies on energy efficiency and renewable energy, continued energy price reform and restructuring of the power sector, and, prospectively, introduction of a carbon price are all suited to advance decarbonization of the power sector.

Emissions growth in Vietnam will be primarily driven by the energy sector (see Section 5.10). Despite an already high electrification rate, the country is planning for electricity demand growth to quadruple by 2030 (Government of Vietnam, 2016). Much of this growth is projected to come from coal (GDE, 2017; IEA, 2017a), of which the country possesses ample domestic reserves. Agriculture, while still an important source of emissions, is declining in relative importance, and industry and waste each contribute only a small share of the country's emissions.

Policy recommendations should therefore focus on ensuring that new electricity generation capacity is based on renewable energy and natural gas rather than coal and, especially in the short term, curbing energy demand growth as a way to buy time for fuel switching in the electricity sector. Opportunities for both are ample, with significant low- or negative-cost potential documented for energy efficiency improvements in households and industry, and attractive conditions for solar and on- and offshore wind energy deployment (Audinet *et al.*, 2016; GIZ, 2016). Ongoing construction of LNG import terminals will also allow increased use of natural gas in electricity generation (Thomas, 2016).

Vietnam already has a robust foundation for climate policy in place. As a country with centralized, top-down decision-making structures, Vietnam relies on 5-and 10-year planning cycles (Vieweg *et al.*, 2017). Three strategic frameworks guide its policies on climate change mitigation: a National Climate Change Strategy (NCCS), a National Green Growth Strategy, and a National Strategy on Environment Protection. In 2012, Vietnam adopted a National Action Plan on Climate Change for the period 2012–2020, which sets out objectives and a large number of specific programmes and projects.

Institutionally, climate change falls within the purview of the the Ministry of Natural Resources and Environment (MoNRE), which operates the National Committee on Climate Change, an advisory agency that serves as the principal body for overseeing climate change policy. Other relevant ministries include the Ministry of Industry and Trade (MoIT), which is responsible for the energy sector, the Ministry of Planning and Investment (MPI), the Ministry of Agriculture and Rural Development (MoARD), and the Ministry of Finance (MoF).

To address the challenge of energy efficiency, Vietnam adopted a National Strategic Program on Energy Savings and Effective Use (VNEEP) in 2006 (Government of Vietnam, 2006), which has been further operationalized by the Law on Economical and Efficient Use of Energy of 2010, the National Target Programme for Energy Efficiency and Conservation (2012), energy labelling regulations adopted in 2012, the Vietnam Energy Efficiency Building Code of 2013, and numerous implementing decrees and technical standards (Nachmany *et al.*, 2015). These policies have not, however, been able to substantially shift energy demand trends so far (Vieweg *et al.*, 2017).

Aside from shortfalls in the effective implementation and enforcement of extent rules, an important factor have been centrally determined electricity prices, which have been fixed at low, albeit progressive, levels (Ha-duong, Truong, Nguyen, Anh and Trinh, 2016). Although the government has commendably announced a phase-out of fossil fuel subsidies by 2020 (Government of Vietnam, 2016), the block electricity tariffs set by the government are not fully reflective of marginal generation costs and therefore amount to an implicit price support. Not only does this reduce the incentive for energy conservation, it also provides insufficient cost-recovery and return on investment in the power sector (ADB, 2015b).

In 2015, Vietnam adopted a Renewable Energy Strategy for 2030, with targets that represent a declining share of renewables in electricity generation to reflect the faster expansion anticipated for generation from coal and natural gas (IEA, 2017a). This Strategy is largely consistent with the latest iteration of the National Power Development Plan (2016–2030), which envisions the addition of 77 new coal-fired power generation plants by 2030. Several support mechanisms incentivize electricity generation from renewable sources, including feed-in tariffs, net metering, and compensation based on avoided cost, complemented by grid codes, standardized power purchase agreements, and incentives related to corporate income tax, import duties, and land use (Campbell *et al.*, 2018; Cattelaens, 2016).

Although these policies have helped open the electricity sector for private investment, it continues to be dominated by a state-owned enterprise, Electricity Vietnam (EVN). Private investors, which already face greater financial risk and capital constraints than the state-owned EVN (UNDP, 2016), also struggle with fixed electricity rates that are too low to cover capital costs for new investments or recover operating costs for existing power generation (ADB, 2015b). Prices for coal—which is mined by another state-owned enterprise, the Vietnamese National Coal and Mineral Industries Group (VINACOMIN)—are also regulated by the government and, although linked to the international market, considered low.

Taken together, low prices for electricity and coal, modest and unevenly enforced incentives, and an electricity market that creates barriers to private sector entry dampen prospects for energy efficiency improvements and rapid growth in renewable energy generation. With earlier plans to develop nuclear power suspended for reasons of cost, and remaining hydroelectric potential at risk due to climate change, decarbonization of the Vietnamese power sector will rely on natural gas and, increasingly, solar, wind and biomass. Aside from reduced externalities, the latter three also offer the benefit of improved energy security through independence from energy imports. Existing policies provide a solid basis for their promotion, but the effectiveness of this policy framework could be enhanced with more ambitious targets, and strengthened institutional capacities to ensure rigorous enforcement (Vieweg *et al.*, 2017).

Importantly, continued restructuring of the power sector can be an important enabler of scaled-up investment in clean energy technologies. As the ongoing power sector reforms (ADB, 2015c; Pranadi, 2018) spur a transition from an electricity market design with state monopolies and centrally controlled prices to a competitive electricity market in which market dynamics determine prices, reenewable energy sources, natural gas, and energy efficiency investments will become more cost competitive. Greater competition will also reduce emissions through operational and efficiency gains, as inefficient and emissions intensive coal fired plants see less frequent dispatch or exit the market (World Bank, 2017).

Leveraging the signaling effect of prices that more accurately reflect underlying cost also requires thinking about carbon pricing over time. In a competitive electricity market, a carbon price will further strengthen the merit of lower-carbon technologies relative to coal, for instance by promoting fuel switching from coal to gas. Vietnam already announced in 2012 that it would launch a national emissions trading system for carbon covering all major emitting sectors (Vieweg *et al.*, 2017). For the carbon price to be effective, however, continued equitization of state-owned enterprises and deregulation of electricity tariffs will be critical to foster responsiveness to market signals. Ultimately, a carbon price will also help channel private sector finance to low-carbon investments, helping overcome another major barrier for mitigation efforts faced in Vietnam.

6.5 Comparison of Results for Indonesia and Vietnam

For both Indonesia and Vietnam, unsurprisingly, meeting larger emission reductions associated with conditional targets (compared to unconditional goals) results in higher carbon prices, larger reductions in GDP and larger changes in electricity generation, primary energy, and sectoral output. Another similarity in both countries, is that a significant share of total emissions come from sectors that do not produce electricity or energy-intensive sectors. Consequently, for both Indonesia and Vietnam, specifying policies to abate emissions in agriculture and other non-energy sectors significantly lowers the carbon price and the GDP cost of reducing emissions, relative to focusing solely on energy and energy-intensive sectors.

Turning to differences in results for the two countries, meeting an unconditional target in Vietnam requires lower carbon prices and lower GDP costs than in Indonesia. This is because Indonesia's unconditional reduction in emissions relative to BAU (16%) is more ambitious than Vietnam's (8%). For each nation's conditional target, the opposite is true: larger proportional emission reductions in Vietnam (25%) than in Indonesia (20%) result in higher emissions prices and GDP costs in Vietnam.

Lessons Learned

Reductions in GHG emissions are achievable at a manageable cost. For an economy-wide policy, the GDP cost in Indonesia and Vietnam is only 0.03% and 0.008%, respectively, relative to GDP in the BAU (No Policy) scenario in 2030. Deviations from the most efficient policy increase the costs. An emissions trading scheme (ETS) applied to only the energy-intensive industries induces "emissions leakage"—an increase in activity and GHG emissions in the uncovered sectors—and thus requires a higher carbon price (roughly 3 times larger in Indonesia and 3 to 7 times larger in Vietnam) than would an economy-wide ETS.

The most extreme simulated impacts arise from meeting conditional targets using an ETS with coverage of only energy-intensive industries (CON-SEL scenario). In Indonesia, this scenario decreases electricity generation in 2030 relative to the BAU by nearly 25% while in Vietnam electricity generation decreases 27.6%. The key insight from these simulations is that the sectoral coverage of climate policy should be a broad as possible. This can be achieved by either including as many sectors as possible in the ETS, or linking non-ETS sectors to included sectors by allowing domestic offset credits to be surrendered in lieu of ETS permits.

Digitalization measures can support the dual-pursuit of development and climate policy goals, with up to a $1.8 billion (0.1%) increase in GDP and 14.6 TWh (2.6%) increase in electricity generation in Indonesia, and up to a $1.7 billion (0.3%) increase in GDP and 8.7 TWh (2.4%) increase in generation in Vietnam, in 2030 relative to scenarios without digitalization.

The key insight from these simulations is that the sectoral coverage of climate policy should be as broad as possible.

This can be achieved by either including as many sectors as possible in the ETS, or linking non-ETS sectors to included sectors by allowing domestic offset credits to be surrendered in lieu of ETS permits.

7 Experience in Other Regions with Policy Measures to Reduce Emissions

Main Takeaways

- Different jurisdictions have adopted very different climate policy portfolios to achieve their mitigation targets. Differences in approaches reflect levels of development, economic and market structures, emissions profile and energy mix, institutional and regulatory circumstances, and other factors.
- No single policy prescription can fit all circumstances. Still, jurisdictions that have pioneered a particular policy instrument often have an extensive body of experience, adding empirical observation to theoretical understanding of how policies work.
- Pathways of policy diffusion are well-documented in the literature, and allow identification of best practices in climate policy design and implementation. Studying the lessons learned in other jurisdictions can help ASEAN nations to avoid costly pathways and reap the full benefits of a robust climate policy portfolio.

As Section 5 shows, ASEAN countries have already set out a number of policies and strategy roadmaps to mobilize climate change mitigation and adaptation. Still, the analysis of emissions trajectories and pathways to NDC achievement has equally underscored the need for additional policy efforts, which will, over time, also necessitate a shift from policies currently in use to new policy approaches, such as carbon pricing. Given different timelines of economic development and environmental policy adoption, a number of countries have already built an extensive body of experience with available policy instruments. Such experience is built on regionally specific circumstances, however, and not all lessons can be directly transferred to the ASEAN region. Still, the insights from studying other countries can be a significant asset when choosing and designing policies that are appropriate for the regional context in ASEAN countries. Below, we highlight the most important positive and negative experiences made with a number of policies considered exemplary for the main policy instrument categories introduced in Section 4.1. Any selection is, to some extent, subjective, but the collective lessons that can be gained from the following case studies should offer guidance for many of the most persistent policy design and implementation challenges encountered in the elaboration of a climate policy mix.

7.1 Promoting Renewable Energy: Price Supports and Auctions

7.1.1 Germany's Feed-in Tariff

Environmental Effectiveness	Cost Effectiveness
Successful at stimulating rapid renewable energy growth, particularly at early maturity stage	Relatively high cost per unit of abatement (avoided emissions), especially if not closely linked to declining technology cost
Distributional Impacts	**Institutional Feasibility**
Concerns about regressive nature, with home- and land-owners more likely to benefit, and surcharge disproportionately affecting low-income households	Basic instrument relatively easy to implement; increasing complexity with greater differentiation; political and planning challenges due to unpredictable outcomes

Lessons Learned

Because of the guaranteed revenue they provide, feed-in tariffs have proven highly effective at stimulating strong growth in renewable energy, especially small-scale distributed generation. As a price-based approach, however, they also create a degree of uncertainty about the scale and speed of actual renewable energy deployment. High or static tariff levels risk offering overly generous returns on renewable energy investment, which in turn can prompt unsustainable cost and penetration growth. Modifications of the feed-in tariff—including automatic tariff adjustments linked to quantity thresholds, and a narrower scope of eligible projects—have helped address these challenges, but also weakened the impact of the feed-in tariff. Meanwhile, utility-scale generation has transitioned to auction-based remuneration systems, providing greater certainty about deployment trajectories.

In recent decades, Germany has built a reputation as a leader in energy sustainability and as an influential actor in climate policy. A central feature of its climate strategy is the *Energiewende*, or energy transition, which—although rooted conceptually in discussions dating back to the early 1980s (Krause *et al.*, 1980)—was formally enacted with a strategy document in September 2010, and sets out a broad framework for German climate and energy policy until 2050. This energy policy defines ambitious targets for the medium and longer term: primary energy consumption is to fall by 20 percent from 2008 levels by 2020, and at least 50 percent by 2050; renewable energy is to account for 18 percent of final energy consumption in 2020, and at least 80 percent of electricity consumption in 2050; and greenhouse gas emissions are to see cuts of 40 percent by 2020 and at least 80 percent by 2050, both relative to 1990 levels.

While achievement of the greenhouse gas reduction and energy efficiency targets is imperiled and expansion of renewable energy in heating and transport fuels has lagged behind expectations, the share of renewable energy in electricity generation has seen remarkable growth in recent years. Coming from less than 3.5% of gross electricity consumption in 1990, it has risen to more than 31% in 2016, with most of the growth occurring within the last decade (BMWiE, 2017). Accompanying this rapid growth in renewable energy production have been a number of broader economic benefits, including net positive employment effects (O'Sullivan *et al.*, 2016). But the rapid penetration of renewable energy in the electricity mix has not been without challenges. Given that nearly half of renewable energy generation capacity is owned by individuals and cooperatives, incumbent generators have suffered a substantial loss in market share, and also seen profit margins shrink as low-variable cost renewable sources increasingly displace conventional sources from the dispatch merit order, exerting downward pressure on average wholesale electricity prices. Also, persistently low carbon prices in the European Union Emissions Trading System (see next subsection) have favored expanding combustion of domestic lignite over cleaner natural gas, exerting upward pressure on greenhouse gas emissions from the power sector. Year-on-year growth in net electricity exports to neighboring countries, made possible by the EU's common electricity market and good cross-border interconnections, has exacerbated this trend.

A key policy responsible for this dynamic growth is the feed-in tariff, which was first introduced with the Electricity Feed in Act (*Stromeinspeisungsgesetz*) of 1990. Conceptually a simple policy instrument, the feed-in tariff guaranteed grid access and set out volumetric tariffs for electricity generated from renewable sources, guaranteeing these for 20 years. Although not a subsidy in the formal sense, with remuneration distributed directly from electricity ratepayers to beneficiaries and not funded by the public budget, the price support and its guaranteed duration were considered reliable enough to attract substantial investment and lower capital cost. In 2000, the underlying legislation was amended to become the Renewable Energy Act (*Erneuerbare-Energien-Gesetz*), with differentiated tariffs reflecting the cost of renewable technologies and specified capacity thresholds, and a year-on-year decline in the rate offered to new generators for 20 years in order to stimulate cost reductions along the renewable technology supply chain. Faster than anticipated technology cost declines, especially for solar photovoltaic installations, sharply increased the effective return on investment, and prompted a surge in small-scale capacity additions between 2008 and 2013.

Conceptually a simple policy instrument, the feed-in tariff guaranteed grid access and set out volumetric tariffs for electricity generated from renewable sources, guaranteeing these for 20 years.

Because this growth threatened a politically untenable rise in ratepayer surcharges and, if extended without any central planning or coordination, would have outpaced necessary grid infrastructure development, the Renewable Energy Act was successively amended in 2012, 2014 and 2016 to increase the role of market signals when determining renewable energy support, while also introducing greater certainty on the scale and speed of deployment. Accordingly, feed-in tariffs have been replaced with quantity-based auctions for all installations other than small-scale distributed installations, tariff levels are automatically adjusted once renewable energy growth falls outside defined boundaries, and recipients of feed-in tariffs are encouraged to switch to self-consumption or opt for market premiums. Already, these changes have shifted the growth dynamic from small-scale residential to larger utility-scale deployment, notably of offshore wind generation. Although criticized by stakeholders in the renewable energy sector for dampening the expansion of renewables, the measures have introduced a greater degree of quantity certainty for infrastructure planning and grid operation.

7.1.2 Renewable Energy Auctions

Environmental Effectiveness	Cost Effectiveness
By allowing regulators to specify the amount of renewable energy from the outset, auctions offer a high degree of certainty in achieving the desired electricity mix. Existing generaton assets are only indirectly affected, however—fundamentally altering the existing generation fleet in the short term may necessitate other instruments, such as technology and performance standards.	By fostering robust competition between bidders and offering long-term fixed contracts and thus stable revenue flows to winning bids, auctions have proven very successful in driving down the cost of renewable energy projects. Given very low bids and tight margins in several recent auctions, however, questions have been raised about the financial viability of projects and thus timely delivers.
Distributional Impacts	**Institutional Feasibility**
Qualification requirements to participate in bidding as well as typically large transaction volumes and project sizes tend to favor institutional bidders. While a factor that has helped drive down cost per unit of renewable energy delivered, this will also affect the distribution of renewable energy investment and ownership. Other tools—such as feed-in tariffs—are therefore better suited to promote distributed generation.	Many jurisdictions already have experience with auctioning in the procurement of conventional energy or other goods and services. Where available, renewable energy auctions can build on existing institutional frameworks and experiences. An enabling regulatory and institutional context—including aligned permitting, grid access and transmission planning—as well as favorable financing conditions are also critical for the success of renewable energy auctions.

Lessons Learned

Within less than a decade, renewable energy auctions have grown to become a key instrument in the toolbox of clean energy support policies. As a quantity-based instrument, they offer greater certainty about renewable energy deployment rates than feed-in tariffs, while still leveraging the static and dynamic efficiencies of market-based instruments. Because the bid awards define the contract price, they also offer price certainty, making them a hybrid instrument that is particularly suited for renewable energy markets that have reached a level of maturity. Their ability to spur competition and incentivize strategic behavior requires an appropriate auction design with robust eligibility or pre-qualification requirements, such as bid and substitution bonds, as well as, where needed, penalties. Experience in Brazil has evidenced the remarkable ability of auctions to drive down contracted wind energy prices, leveraging a two-part auction design; but it has also seen considerable delays and delivery shortfalls, underscoring the importance of enabling conditions, such as a smooth permitting process, forward-looking transmission planning, and access to finance. Local content requirements, while accelerating growth of a domestic renewable energy industry, have also proven a factor in project delays.

Renewable energy auctions have emerged as a popular mechanism to promote renewable energy technologies. Renewable energy auctions involve a government or other actor issuing a call for tenders to procure a certain capacity or generation of electricity based on renewable sources. Bidders compete to deliver these volumes, and the bid with the lowest required support level typically wins the auction (Mora *et al.*, 2017). As a policy option, auctions have attracted growing attention given their ability to secure deployment of renewable electricity in a planned and cost-effective manner, combining a number of advantages: flexibility, real price discovery, greater certainty in price and quantity, and the ability to guarantee commitments and transparency (IRENA *et al.*, 2015). Rapidly decreasing renewable energy technology costs, more mature supply chains, improved access to capital and growing experience with auctions have leveraged their inherent ability to spur price competition and driven down the costs of new renewable energy deployment to remarkable levels in recent years.

By 2016, 67 countries had used auctions for renewable energy contracts, up from less than 10 in 2005; average contract prices fell to USD 50/MWh for solar and USD 40/MWh for wind power in 2016, compared to USD 250/MWh and USD 80/MWh, respectively, in 2010 (IRENA, 2017). In the past two years, Chile, India, Mexico, Morocco, Peru and the United Arab Emirates have attracted international media attention for the record price lows achieved with solar and wind auctions. In Mexico, a recent auction for long-term renewable energy procurement, held on 15 November 2017, included an award of wind projects at the record low price of $17.7/MWh (Hill, 2017). But these low prices, while attesting to the cost effectiveness of auctions as a policy to support renewable energy deployment, also raise concerns about underbidding, project delays and project failure.

It is in the nature of auctions as a competitive allocation mechanism that not all viable projects can be developed, forcing the renewable energy sector to adopt strategic behavior. Auctions therefore need to be designed in a manner that ensures sufficient competition for robust price formation and avoids undesired strategic incentives, collusion, and other market distortions, all while addressing the risk of low realization rates (Mora *et al.*, 2017). Stringent bidding requirements (e.g. financial, environmental, and grid connection requirements) and compliance rules (e.g. penalties, bid bonds, and project completion guarantees) are therefore a key aspect of any renewable energy auction (Tongsopit *et al.*, 2017). As with other support policies, the successful implementation of auctions relies on an appropriate regulatory and institutional framework, relevant skills, and adequate infrastructure to attract investors (IRENA, 2013). Leveraging experience with auctions for public procurement of other goods and services, as well as existing auctioning platforms and institutional knowledge, can help ensure robust implementation. Transparent processes, adequate timelines, as well as training and capacity building for prospective bidders can all help increase participation and successful bidding. Often, however, the design solutions will be highly specific to a given context, and may involve trade-offs: pre-qualification rules and penalties can increase realization rates, for instance, but can also increase the risk and thus the costs for bidders (Mora *et al.*, 2017).

> ***Auctions must be designed to ensure sufficient competition for robust price formation and avoid undesired strategic incentives, collusion, and other market distortions—while at the same time addressing the risk of low realization rates.***

In Brazil, auctions have been used to determine remuneration rates for renewable energy since 2007, offering one of the longest continuous track records for the use of this instrument in practice. Wind energy, in particular, has benefited from the auctioning system, driving the largest expansion of wind generation capacity worldwide in 2013 and 2014 (Bayer 2018). In part, this strong result has been due to a hybrid auction design that has spurred competition and lowered prices, using an open-bid descending clock auction to identify the price ceiling, and following with a sealed-bid auction to determine the final price. By including a local content requirement for wind energy equipment, moreover, the auctioning approach has also promoted the emergence of a domestic wind industry in Brazil. Still, the Brazilian experience has not been an unqualified success. Completion deadlines for wind power projects contracted under the earliest auctioning rounds

> ***In Brazil, auctions have been used to determine remuneration rates for renewable energy since 2007, offering one of the longest continuous track records for the use of this instrument in practice.***

have already expired, providing insights into actual realization rates and the role of compliance and enforcement mechanisms. What emerges is a mixed picture, with policy and regulatory constraints also responsible for significant delays in project implementation. Below follows an outline of the evolution and design of wind energy auctions in Brazil, as well as a summary of the main lessons learned there from nearly a decade of implementation.

Faced with high energy demand growth in the early 2000s, Brazil initially relied on a feed-in tariff policy, the Program of Incentives for Alternative Electricity Sources (PROINFA), as its main incentive for expansion of renewable energy capacity. Conceptually, this policy was broadly modeled after the German Renewable Energy Act described in the previous section, but faced numerous implementation challenges and delays (IRENA, 2013). Starting in 2004, Brazil began resorting to auctioning of short, medium and long-term energy contracts as a mechanism to ensure adequacy of supply. Under this policy framework, it was also able to introduce technology-specific auctions, commencing with biomass and small hydroelectric generation contracts in 2007, and adding wind energy auctions from 2009. These auctions are led by the electricity regulatory agency, or Agência Nacional de Energia Elétrica (ANEEL), based on guidelines set out by the Ministry of Energy and Mines (MME). Together with the Chamber for Commercialization of Electrical Energy (CCEE) and the Energy Research Company (EPE), ANEEL announces and designs the auction, suggests price caps, prepares the auction documents, and coordinates transmission planning (Förster *et al.*, 2016).

Auction volumes are informed by load forecasts from the distribution companies. Based on the declared power requirements, ANEEL carries out a centralized procurement process roughly twice a year for new energy, with successful bidders entering into bilateral delivery contracts with distribution companies. Projects are contracted to begin delivery after a specified number of years (generally three or five), and typically extend to 30 years for hydropower and 20 years for wind and biomass. Contracts are indexed to the consumer price index, and have to be covered by Firm Energy Certificates (FECs) to back up load growth forecasts of distribution companies. Additionally, reserve auctions are carried out periodically to contract surplus energy and increase reserve margins in the Brazilian electricity system. Unlike new energy auctions, the resulting contracts with the CCEE do not have to be backed by FECs (Förster *et al.*, 2016).

As for the auctioning mechanism, a first stage uses a descending price clock auction to discover the price ceiling, and a second stage solicits final sealed bids to meet actual demand. In order to be qualified, candidates for auctions must possess a prior environmental license, a grid access approval issued by the system operator, and resource assessment measurements undertaken by an independent authority. Bidders also have to deposit a bid bond equal to 1% of the estimated project cost, and auction winners have to deposit a project completion guarantee equal to 5% of the investment cost, which is subsequently released after certain project milestones are met. For wind power auctions, moreover, a local content requirement calls for 60% of wind equipment to be purchased from national manufacturers. Various penalties and adjustments apply to violations of the contract terms, such as delays, excess generation or generation shortfalls. The ability to carry over deviations from the contracted production commitment for a period of four years provides some flexibility (Förster *et al.*, 2016).

In 2009, Brazil carried out its first technology-specific auction for reserve energy from wind generation. 441 projects registered for this auction, out of which 339 met all qualification requirements. In the end, 71 projects amounting to 1,806 MW were selected at an average price of USD 84/MWh. By 2011, wind had already outbid natural gas in technology-neutral auctions with an average price of USD 63/MWh (IRENA, 2013). After four years of significant decreases, however, wind auction prices in Brazil have been growing again due to regulatory changes such as a modification of grid connection terms, as well as external factors such as the falling value of the Brazilian currency against the US Dollar (Bayer, 2018).

One of the central lessons learned from the Brazilian experience with wind auctions has been the usefulness of technology-specific auctions initially to help renewable resources become competitive, allowing them to now bid viably alongside conventional resources in technology-neutral auctions. Long duration of contracts and their indexation to the local consumer price index offer attractive risk protection to investors by ensuring constant and predictable remuneration levels (Maurer *et al.*, 2011), which in turn eases financing (del Rio *et al.*, 2014). Local content requirements, while problematic under international trade law, have helped attract foreign investment and prompted the entrance of several technology providers into the Brazilian market, resulting in the development of a mature domestic industry and sufficient competition to ensure free price formation in the market (Cozzi, 2012). Growing experience of actors and increased levels of competition among project developers, investors and turbine manufacturers were instrumental in driving down wind auction prices, although the competition driven by the hybrid auction design has also exerted intense pressure on investment returns and called into question the financial viability of some projects (Förster *et al.*, 2016).

One of the central lessons learned from the Brazilian experience with wind auctions has been the usefulness of technology-specific auctions initially to help renewable resources become competitive, allowing them to bid viably alongside conventional resources in technology-neutral auctions.

Meeting the 60% local content requirement has proven challenging at times, moreover, causing supply bottlenecks and holding back project implementation (IRENA, 2013). Regulatory constraints, such as delays in securing environmental permits, as well as grid access delays due to inadequate transmission planning, have been cited as further factors affecting timely project completion. Under the first eight auction rounds carried out between 2009 and 2015, only 14% of the awarded wind projects were therefore completed on schedule (Bayer, 2018). Still, few projects have been cancelled altogether, and one study suggests the final rate of completion will lie between 89% and 98% (Bayer, 2018). More recently, stalling capacity needs due to the current economic recession have resulted in the cancellation of some energy auctions in Brazil (Renewables Now, 2016), and falling solar photovoltaic technology costs have seen that technology dominate in the latest renewable energy auctions (Renewables Now, 2018). Together, these factors portend a more challenging market environment for wind energy in the near term, although they do not necessarily invalidate the favorable assessment of auctions as an instrument to promote clean energy: a changing economic context, delays in infrastructure planning and deployment, as well as falling costs of competing technologies cannot be ascribed as a failure of auctions. If anything, the Brazilian experience highlights the welfare-maximizing effect of auctions by not forcing continued expansion of one particular technology despite lacking demand and cheaper renewable alternatives.

7.2 Promoting Energy Efficiency: Performance Standards, Subsidies, and Quota Trading

7.2.1 U.S. CAFE/Tailpipe Emission Standard for Vehicles

Environmental Effectiveness	Cost Effectiveness
Provided the policy is adequately monitored and enforced, the mandatory nature of fuel economy standards guarantees achievement of environmental outcomes	Widespread consensus in the academic literature that fuel economy standards are highly inefficient in terms of cost per emissions abated
Distributional Impacts	**Institutional Feasibility**
Some degree of regressivity of fuel economy standards is likely when considering their impact on used car sales	Politically often justified with energy security considerations; administrative complexities manageable; political pushback from stakeholders due to compliance cost may weaken policy durability

Lessons Learned

Due to their mandatory nature, fuel economy and emission performance standards provide reasonable certainty about the achievement of environmental outcomes. Conceptually, they help address market failures such as the bounded rationality of vehicle buyers, and information asymmetries between regulatory, manufacturers and consumers. Politically, they have frequently been justified with energy security and geopolitical concerns, however, and have typically been able to secure public acceptance. As a climate policy measure, however, they come at significant economic cost, suggesting alternative measures would be more cost-effective for each unit of emissions abated. Unfavorable distributional impacts, moreover, and stakeholder pressure may undermine political support.

In 2016, after years of falling greenhouse gas (GHG) emissions from electricity generation, the transportation sector became the single largest source of emissions in the U.S. (EIA, 2017: 184). It was the first target of executive climate action during the administration of President Barack H. Obama, when the EPA and the National Highway Traffic Safety Administration (NHT-SA) drew on rulemaking authorities under the Energy Policy and Conservation Act (EPCA, 1975) and the Clean Air Act (CAA, 1963)[1] to issue joint Corporate Average Fuel Economy (CAFE) and greenhouse gas (GHG) emissions standards for passenger cars and light trucks manufactured between 2012 and 2016. In this first phase, new vehicles sold in the U.S. are mandated to achieve an average fuel efficiency of 35.5 miles per gallon by 2016, based on a CAFE standard of 34.1 miles per gallon and a GHG emissions limit of 250 grams per mile (NHTSA/EPA, 2010). These standards are projected to save 61.0 billion gallons of fuel and reduce GHG emissions by 654.7 million metric tons over the lifetimes of the sold vehicles (NHTSA, 2010). Similar standards have also been adopted for medium and heavy-duty vehicles produced between 2014 and 2018.

A second phase would require passenger cars and light trucks manufactured between 2017 and 2025 to achieve a fleet average of 54.5 miles per gallon by 2025, equalling an average industry level of approximately 163 grams/mile of carbon dioxide (CO_2) in model year 2025 (NHTSA/EPA 2016), and contributing to a projected reduction of tailpipe GHG emissions by 2 billion metric tons over the lifetime of vehicles sold during that period (EPA, 2012). The current administration has reinstated a midterm evaluation of the standards, expressing concern

1 88th Congress, H.R.6518, 'An Act to Improve, Strengthen, and Accelerate Programs for the Prevention and Abatement of Air Pollution (Clean Air Act)' (17 December 1963), as amended in 1967, 1970 and 1990, 42 U.S. Code Chapter 85 § 7401. In 2007, U.S. Supreme Court had determined in *Massachusetts v Environmental Protection Agency et al.* [2 April 2007] 549 US 497 (2007) that the EPA could regulate greenhouse gas (GHG) emissions if it was able to conclude that, by causing or contributing to climate change, these GHGs endanger both public health and the public welfare of current and future generations. Late in 2009, the EPA issued such a finding, see 'Endangerment and Cause or Contribute Findings for Greenhouse Gases under the Section 202(a) of the Clean Air Act', of 7 December 2009, 40 CFR Chapter I (2009) 74(239) Federal Register 66496.

about the economic burden of these standards relative to the GHG emissions reductions and fuel savings they would achieve (DOT and EPA, 2017). A determination is expected by 1 April 2018. Academic analysis has widely concluded that fuel economy and emissions standards are costly relative to the achieved emission reductions (see e.g. Karplus and Paltsev, 2012), and recent research also suggests they are regressive in terms of how compliance costs are passed through to consumers (Davis and Knittel, 2016). Moreover, following a period of low gasoline prices, the structure of the vehicle fleet has evolved due to changing consumer preferences, generating concerns that fuel economy mandates—although at one point agreed with vehicle manufacturers during stakeholder consultations—may now incur substantially higher compliance costs than originally expected.

7.2.2 India's Perform, Achieve and Trade (PAT) Scheme

Environmental Effectiveness	Cost Effectiveness
Aggregate energy efficiency targets have been overachieved, suggesting significant potential for increased ambition. Penalties against non-compliance provide assurance of target achievement.	Covered entities are able to purchase ESCerts in lieu of implementing energy efficiency improvements in their own facilities. This increases compliance flexibility and thereby reduces cost.
Distributional Impacts	**Institutional Feasibility**
Because a great majority of covered entities has been able to achieve their targets without ESCert purchases, PAT has not resulted in significant redistribution of wealth. Studies of cost pass-through and how this might affect final consumers have not yet been made.	New institutions had to be created and institutional mandates and capacities expanded to administer the PAT scheme. Administrative structures established and energy use data collected under existing energy conservation rules have helped reduce necessary institutional changes.

Lessons Learned

White certificate trading systems have been in place in a number of jurisdictions. Their appeal lies in bringing the economic efficiency benefits of market-based instruments and trading to bear on energy conservation, where policies have tended to be dominated by more traditional—and typically costlier—technology and performance standards. India's PAT is an interesting example in that it deploys a white certificate trading system as the main instrument to drive energy savings from large industrial energy users. Although targets in the first compliance phase have been modest and trading in the market for certificates consequently thin, the substantial overachievement of targeted energy savings reflects the potential of the PAT scheme as an instrument of clean energy policy.

For India, which has the third-largest energy demand in the world, improved energy efficiency is key to addressing a threefold challenge: expanding energy access; safeguarding energy security; and addressing climate change (Bhandari *et al.*, 2018). Since 2012, the Perform, Achieve and Trade (PAT) scheme has been the country's flagship instrument to reduce industrial energy consumption in India. It represents an innovative approach to improving demand-side efficiency in energy intensive industries, and deploys a market-based mechanism to enhance the cost-effectiveness of energy conservation measures (CDKN, 2013). PAT was announced by the Indian Government in 2008 under its National Mission on Enhanced Energy Efficiency (NMEEE), a part of the National Action Plan on Climate Change (NAPCC), and implemented through a 2010 amendment to the Energy Conservation Act (ECA) of 2001.

Participation in the scheme is mandatory for larger, energy-intensive facilities that exceed sector-specific energy consumption thresholds and are listed as Designated Consumers (DCs) in the ECA. Eight energy-intensive sectors were included from the outset: aluminum, cement, chemical industry (chlor-alkali and fertilizer), iron and steel, pulp and paper, textiles, and thermal power plants. Together, these sectors account for roughly 60% of India's total primary energy consumption. Already prior to the introduction of PAT, these entities were subject to certain compliance obligations under the ECA, such as conducting mandatory energy audits through accredited auditors, appointing designated energy managers at each plant, and periodically reporting energy consumption data. As India proceeded to introduce the PAT scheme, these obligations helped build technical capacity within both the administration and the private sector, and also provided a solid foundation of facility-level energy consumption data.

PAT is being implemented in three phases, with the first phase running from 2012 to 2015 and covering 478 facilities. For each phase, participating DCs are assigned targets for reductions in their specific energy consumption (SECs), calculated against a benchmark based on the best performing plant within each sector. Historical energy consumption data declared by each facility and verified by accredited energy auditors serves as a baseline, with targets defined as a percentage reduction from that baseline. For the first phase, the baselines were drawn from the historic energy consumption of each DC between 2007 and 2010, and adjusted to achieve an aggregate reduction in energy consumption of 6.6 million tons of oil equivalent, with an average reduction target for facilities amounting to 4.8% (Dasgupta *et al.*, 2016). A process of normalization is used to correct for factors affecting specific energy consumption that are beyond the control of participating DCs, such as a changes in the product mix, capacity utilization, or fuel quality (Sahoo *et al.*, 2018). Verification of the performance of DCs at the end of the cycle is carried out by energy auditors accredited by the Bureau of Energy Efficiency (BEE), an agency under the Ministry of Power of India. At the end of a phase, covered entities which have been able to reduce energy use beyond their SEC target and have had these energy savings verified are issued energy savings certificates, or ESCerts, which they can then sell to entities that have failed to meet their SECs. Each ESCert represents 1 ton of oil equivalent. A newly established company, Energy Efficiency Services Ltd. (EESL), administers the trading of energy savings certificates.

Between 2012 and 2015, PAT has been credited with achieving energy efficiency improvements equivalent to 31 $MtCO_2$, exceeding the original target by over 30%. All sectors except for the thermal power generation sector surpassed their targets (IEA, 2018). Interviews with covered entities suggest that PAT has not been "additional" as a policy, and that a majority of energy efficiency improvements credited to PAT would have also occurred in a business-as-usual scenario due to increasing energy costs; for that to change, commentators have called for more ambitious energy efficiency improvement targets in subsequent phases (Bhandari *et al.*, 2018). So far, however, only limited details have been published about the further evolution of PAT. In the current second phase, coverage has expanded to include 727 facilities in eleven sectors, adding refineries, railways and distribution companies. Likewise, the nominal mitigation target has increased to 30 $MtCO_2$ in the second phase. Because of the relatively short length of compliance phases, critics have implied that PAT fails to convey the necessary price signal for long term investment in energy savings (Bhandari *et al.*, 2018). Still, fears that modest targets would stifle demand for ESCerts and thus the emergence of a robust market have been proven wrong: weekly volumes of traded ESCerts have exceeded one million units in early 2018 (IEX, 2018). As with other market-based instruments for environmental policy, however, leveraging the full efficiency benefits of trading will depend on increased policy ambition going forward.

7.3 Carbon Pricing: Emissions Trading and Carbon Taxes

7.3.1 European Union Emissions Trading System (EU ETS)

Environmental Effectiveness	Cost Effectiveness
While the emissions 'cap', or ceiling, has not been breached, price levels have been too low to induce intended dynamic effects, especially for new investment	Despite low allowance prices also being owed to extraneous factors, the market has proven very effective at channeling action to low-cost abatement opportunities
Distributional Impacts	**Institutional Feasibility**
Flexibility in benchmark-based allowance allocation has helped protect energy-intensive, trade-exposed sectors, but also resulted in windfall profits and regulatory capture	Securing reliable emissions and activity data, as well as integrity of the carbon market, have raised administrative and governance challenges; cap-setting and allocation decisions politically complex

Lessons Learned

More than a decade of experience with the EU ETS has yielded valuable lessons on the importance of emissions data availability and quality, the possibility of windfall profits from generous free allocation rules where allowance costs were nonetheless passed through to customers, and the need for robust governance structures for market oversight. Most importantly, the EU ETS underscored how price discovery in emissions trading systems is susceptible to uncertainty and unanticipated shocks. Consistently depressed carbon prices in the EU ETS have prompted successive interventions to prevent undesirable dynamic effects, such as resurging dispatch of, and new investment in, coal-fired electricity generation.

Operational since 2005, the European Union Emissions Trading System (EU ETS) remains the largest emissions trading system currently in operation (Directive 2003/87/EC). It represents a pure form of quantity control policy and lacks the price control elements some hybrid emissions trading systems have introduced. Currently, it operates in 31 countries—all 28 EU Member States as well as Iceland, Liechtenstein and Norway—and covers emissions from emitters in the power sector, aviation, combustion plants, oil refineries, iron and steel works, as well as installations producing a range of products including aluminum, lime, cement, glass, ceramics, bricks, pulp, paper, board, and certain petrochemicals. More than 11,000 covered entities account for around 2 billion metric tons or 45% of EU greenhouse gas emissions, making the EU ETS a centerpiece of European climate policy. Its adoption was based on a competence for environmental policy shared between the EU and its Member States, and as such reflects the particularities of the EU legal system, with objectives, principles and key parameters defined at the level of the EU, and more specific details as well as implementation and enforcement largely devolved to the Member States.

Overall, the EU ETS has been implemented in a phased approach. The general framework is contained in a directive setting out central features such as scope and coverage, issuance of units, and compliance and enforcement. Over a dozen subsequent directives, regulations and decisions elaborate on different aspects of the EU ETS, updating the legal framework to reflect new mitigation targets and a link to international offsets, extending the market to new sectors and gases, establishing common infrastructure such as the Union Registry, and providing technical guidance and procedural detail on design features such as auctioning and MRV. Importantly, governance of the EU ETS evolved significantly over the three initial trading periods (2005–2007, 2008–2012 and currently 2013–2020), with competences in a number of areas—such as allocation of units and registry operation—becoming successively more centralized when implementation at Member State level proved inadequate.

Features not yet envisioned in the original directive were added over time in response to observed regulatory gaps or design shortcomings. Persistent volatility of prices in the carbon market as well as prolonged price weakness due to macroeconomic cycles, greater than expected mitigation from complementary policies, and extensive introduction of offset credits (Koch *et al*., 2014), have been two of the features that have attracted the greatest criticism in the implementation of the EU ETS. A delay in the scheduled auction of allowances ('back-loading') as well as the introduction of a dynamic supply adjustment mechanism, the Market Stability Reserve (MSR), have been adopted to address these shortcomings. Likewise, a string of incidents involving market abuse and fraud in recent years have resulted in the inclusion of both primary and secondary emissions markets in the scope of financial market regulations. The latest legislative revisions for the fourth trading period (2021–2030), preliminarily agreed through a high-level compromise in November 2017, are expected to further strengthen the price signal delivered by the EU ETS with a steeper emission reduction pathway and accelerated withdrawal of surplus allowances into the MSR.

7.3.2 Regional Greenhouse Gas Initiative (RGGI)

Environmental Effectiveness	Cost Effectiveness
An initially generous emissions cap was partly offset by smart investment of auctioning revenue. Subsequently, the cap has been strengthened, and design adjustments will help avoid price weakness	Considerable reductions have been achieved despite relatively low allowance prices
Distributional Impacts	**Institutional Feasibility**
The impact on electricity prices has been modest, and part of the allowance auctioning proceeds have been deployed to e.g. improve energy efficiency in low income households	Designation of a centralized entity, RGGI, Inc., to oversee key processes under RGGI has proven an efficient way to outsource and streamline the administrative requirements under RGGI

Lessons Learned

Experience under RGGI is notable in that it lends support to the benefits of auctioning as a method of allowance allocation, demonstrating that even an initially weak emissions cap can nonetheless result in emission reductions if the auctioning revenue is invested in abatement measures. It also underscored a positive political economy dynamic of emissions trading systems in that initial price weakness focused policy reform efforts on tightening the cap through cancellation of surplus allowances, a more stringent emissions reduction pathway, and a strengthened design with an intervention mechanism to reduce oversupply of allowances (in addition to the auction reserve price that was part of RGGI from the outset). Also, RGGI exemplifies policy learning from prior experiences, notably the negative experiences with free allocation in the power sector under the EU ETS.

RGGI was the first mandatory U.S. ETS for greenhouse gas emissions and has been operational since 2009. It is a regional effort among a group of states in the U.S. Northeast and Mid-Atlantic: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, Vermont, and possibly joined soon by Virginia. It creates compliance obligations for one sector only: thermal power plants generating electricity with fossil fuels that have a rated capacity of 25 MW or more (currently 16 regulated entities). Its origins date back to 2005, when seven states signed a Memorandum of Understanding (MOU) committing them to stabilize CO_2 emissions from power generation between 2009 and 2015, and thereafter reduce emissions by 10 per cent by 2019. Following a program review in 2012, the RGGI cap was adjusted downward to reflect greater than expected emission reductions by 2020, RGGI is now projected to result in a 45% reduction in the annual emissions from electricity generation relative to 2005 levels. Additionally, a Cost Containment Reserve (CCR) was introduced to provide additional unit supply if prices in the market exceed certain thresholds.

As such, the MOU is not a legally binding instrument, and merely indicates the intent of participating states to implement corresponding state regulations. All binding obligations for compliance entities and state emission budgets are contained in the regulations adopted by each state, which are largely based on a common template, the RGGI Model Rule. The ETS established in each state are linked through reciprocity arrangements with every other state, meaning that regulated entities can use a CO_2 allowance issued by any of the participating states to demonstrate compliance with their obligations. Given the particularities of the U.S. federal system, a central arrangement binding on all participating jurisdictions was not feasible. Instead, RGGI has made extensive use of jointly agreed templates and guidance documents, and is thus characterized by a relatively low degree of formality. Partly offsetting this lack of binding normativity at the central level is a high degree of procedural and institutional coordination through working groups and a designated institution established to provide administrative and technical services to participating states, RGGI Inc., which is organized as a non-profit corporation and has no regulatory or enforcement authority.

On 23 August 2017, the RGGI announced in a press release that the participating states had agreed on draft program elements that will guide the program between 2020 and 2030. A key element of the draft program is a further reduction of the emissions cap to 30% below 2020 levels. Other key elements include the creation of an Emissions Containment Reserve (ECR), modifications to the CCR, and adjustments to the RGGI cap to account for excess unsold allowances that have been banked up to 2020. The ECR is an automatic adjustment mechanism that would start operation in 2021, adjusting the cap downward in the face of lower-than-expected costs. Together, the ECR and the CCR would create a price band between USD 6 and USD 13, both increasing at 7% annually.

Because of the modest initial target, reduced electricity demand due to the economic and financial crisis of 2008–2009, and a significant shift from coal to natural gas for electricity generation, the market was oversupplied with allowances during its early years, causing the allowance price to fall near the minimum clearing price allowed at auction. Despite the low-price levels, however, an independent analysis of the economic impacts of RGGI concluded that RGGI had a positive macroeconomic impact while helping reduce emissions in participating states, mainly through investments in energy efficiency measures and renewable energy deployment which were financed through a share of the auctioning revenue. Specifically, the analysis suggested that the first three-year control period added 1.6 billion USD in net present value (NPV) to the region, with capital flows into economic goods and services as well as ratepayer savings from energy efficiency improvements clearly outweighing net revenue losses in the energy sector (Hibbard *et al.*, 2011). Subsequent assessments have affirmed that conclusion, as well as a growing mitigation effect from the tightened cap (e.g. Hibbard *et al.*, 2015).

7.3.3 Western Climate Initiative (WCI)

Environmental Effectiveness	Cost Effectiveness
A comparatively high Auction Reserve Price has ensure that carbon prices remain at a more robust level than in many other jurisdictions; still, much of the mitigation occurring in the program region has been achieved by complementary policies, such as energy efficiency standards.	Broad coverage and a liquid market have effectively leveraged the cost-reducing potential of economic instruments. Extensive use of overlapping complementary instruments has contributed to emission reductions, however, interfering with the market as a mechanism to allocate reduction effort to the cheapest abatement options.
Distributional Impacts	**Institutional Feasibility**
Revenue from auctioned allowances are partly allocated to disadvantaged communities. In California, in particular, the environmental justice movement has had a strong political impact on system design and implementation. Vulnerable industries at risk of relocation are treated favorable through output-based rebates.	Designation of a centralized entity, WCI, Inc., to oversee key processes under WCI has proven an efficient way to outsource and streamline the administrative requirements under WCI. State and province agencies, such as the Californian Air Resources Board (ARB), are closely involved in all aspects of system design, implementation, review, and enforcement.

Lessons Learned

Dominated by its largest member, California, the WCI has resulted in the creation of the first ETS built on cross-border linkage of sub-national carbon markets. During a time in which the federal governments of Canada and the United States have faced various obstacles to implementing a national carbon price, this example of sub-national cooperation has sent a helpful signal about the viability of climate action at all levels. A favorable political economy and later start date allowed the participating states to achieve a more robust balance of supply and demand in the market, although the Auction Reserve Price has been instrumental in securing the high allowance price with which the WCI credited. Due to its upstream inclusion of transportation and heating fuel, the WCI program design has one of the broadest coverages of any ETS, theoretically increasing overall efficiency. A portfolio of complementary policies to improve energy efficiency and expand renewable energy use in the WCI jurisdictions has lessened the impact of the ETS, however, and diluted some of the cost effectiveness benefits of this quantity rationing instrument.

Similar to RGGI, the WCI is a regional initiative that was launched in 2007 in the absence of federal climate regulation. It differs in important respects, however, both in terms of the design of its ETS and because it allows trading across national borders between subnational jurisdictions in two sovereign countries, the U.S. and Canada. At its establishment, the original signatories Arizona, California, New Mexico, Oregon, and Washington decided to set an overall regional target to lower greenhouse gas emissions by 15% below 2005 levels by 2020 and to develop a design for a regional market-based multi-sector mechanism, with a multi-state registry to enable tracking, management, and crediting for entities that reduce emissions. Over time, additional subnational jurisdictions in the U.S., Canada and Mexico joined as participants or observers, but electoral changes eventually prompted most to abandon the process. Currently, only California, Ontario, and Québec have an operating ETS, although preparations are underway in other Canadian provinces to launch additional ETS.

Preparations for the establishment of a market-based emissions reduction program, including a multi-stakeholder process, resulted in the release of a detailed program design in 2010, which grants substantial autonomy to participating jurisdictions and relies on them for adoption and implementation of appropriate state or provincial rules. At its launch in 2013, the ETS initially covered emissions from the electricity sector and large industrial and commercial sources emitting over 25.000 metric tons of CO_2e per year, extending to emissions from transportation and other residential, commercial, and industrial fuel users beginning in 2015. As with RGGI, Inc., a non-profit corporation, Western Climate Initiative, Inc. (WCI, Inc.), was established to provide administrative and technical services for implementation of the ETS, including the compliance tracking system that tracks both allowances and offsets certificates, the administration of allowance auctions; and market monitoring of allowance auctions and allowance and offset certificate trading.

WCI is based on cooperation between subnational jurisdictions, with federal law restricting binding international commitments and the conferral of legislative or enforcement powers to external entities. Accordingly, the ETS design parameters adopted jointly by WCI partners have the character of recommendations only, with any legal obligations originating purely from the rules elaborated by each jurisdiction in the implementation of its ETS. By far the largest participating jurisdictions is California, whose efforts to develop an ETS build on a comprehensive state-wide act—the California Global Warming Solution Act of 2006 (AB 32)—requiring that state-wide emissions be reduced to 1990 levels by 2020. The California Air Resources Board, under the California Environmental Protection Agency, was tasked with exploring options to establish an ETS, and had substantial influence on the WCI design.

Some unique features of the WCI program include the broad scope, resulting in coverage of around 85% of emissions in the participating jurisdictions; the carbon trading link across national borders; the periodic, cross-border joint auctions; and the early implementation of a price corridor through an Auction Reserve Price and Allowance Price Containment Reserve. In California, moreover, the ETS includes electricity imports (and a prohibition of so-called “resource shuffling”) to avoid emissions leakage to neighbouring states, providing the first functioning example of a border carbon adjustment. WCI will continue to evolve as states and provinces implement new or amend existing carbon pricing policies. In 2017, California agreed an extension of its ETS beyond 2020 with a strong legislative majority, introducing a number of additional features to further strengthen the policy design, and thereby solidifying the nucleus of the WCI carbon market. After Ontario’s ETS began operations at the beginning of 2018, additional Canadian provinces, such as Nova Scotia, are likely to follow suit.

7.3.4 British Columbia Carbon Tax

Environmental Effectiveness	Cost Effectiveness
Although studies show that the carbon tax has contributed to significant emissions reductions relative to the rest of Canada, stagnating tax rates between 2012 and 2018 as well as the potential for leakage due to exemptions for imported electricity and fuel purchased across the border have dampened the environmental benefits.	British Columbia’s carbon tax ranks favorably across several metrics, including the marginal cost of emission reductions, the administrative cost of implementation, and the aggregate welfare impacts. By leveling abatement cost across covered sectors, it has maximized static cost effectiveness. The inclusion of additional GHGs and emission sources, such as industrial process emissions and emissions from land use, land use change, and forestry, could further increase this effect, assuming it replaces existing (non-economic) policies.
Distributional Impacts	**Institutional Feasibility**
Revenue recycling has allowed income tax reductions and directed payments and resulted in what a study affirmed a “progressive” overall effect. The indication of the newly elected left-of-center government may call into question the previous commitment to revenue neutrality, however.	Political economy factors specific to British Columbia allowed passage of the carbon tax, although the use of revenues and astute political messaging helped sustain strong public support. Technically, the carbon tax was relatively straightforward to implement, by adding the tax rate to other taxes already being collected on fossil fuels.

Lessons Learned

British Columbia has been a rare example of a carbon tax that has both been faithful to design recommendations from economic theory, and has enjoyed broad public support. Although a convergence of factors specific to British Columbia favored its passage in 2008, the commitment to revenue neutrality and astute communication of the environmental and economic benefits of its introduction were instrumental in ensuring its sustained popularity and political resilience. Going forward, the carbon tax will have to be further increased to achieve the long-term mitigation targets enacted by British Columbia, and its limited scope (exempting industrial and land use emissions) as well as the potential for emission leakage through cross-border fuel and electricity purchases.

On 1 July 2008, Canadian province British Columbia introduced a carbon tax at a rate of CAD 10 per metric ton of CO_2e emissions, increasing by CAD 5 per ton each year until reaching the current level of CAD 30 per ton in July 2012. With limited exemptions—such as exported fuels and aviation or shipping fuels—the carbon tax covers all fossil fuels used within the province, including liquid transportation fuels such as gasoline and diesel, as well as natural gas or coal used to generate electricity. The tax rate per ton of CO_2e is translated to the type of fuel used, based on its carbon content using 100-year global warming potential values, and assessed per units of sale at the point of purchase (Murray *et al.*, 2015). Current rates for select fuels are provided in Table 7.3.1.

In relative terms, the tax accounts for a comparatively modest share of the final price for highly processed fuels, such as gasoline, diesel, and propane, but can account for a large share of the price of natural gas and coal. With the foregoing coverage, the tax accounts for around 75% of all GHG emissions in the province. Not covered are CO_2 emissions from industrial processes and forestry, CH_4 emissions from land use, land use change and forestry as well as natural gas operations, and N_2O emissions from agriculture (British Columbia, 2015).

Table 7.3.1: Carbon Tax Rates for Select Fuels (in CAD, based on British Columbia, 2015)

Fuel	Tax Rate (based on CAD 30/ton CO_2e)
Gasoline	6.67 ¢/liter
Diesel (light fuel oil)	7.67 ¢/liter
Natural gas	5.70 ¢/cubic meter
Propane	4.62 ¢/liter
Coal (high heat value)	62.31 CAD/ton
Coal (low heat value)	53.31 CAD/ton

The revenues raised with the carbon tax, approximately CAD 1 billion each year, are redistributed back to households in the form of personal and corporate income tax reductions or direct transfers, reflecting the goal of revenue neutrality. Specifically, the revenue has enabled:

- A 5% reduction in the first two personal income tax rates;
- Reductions in the general corporate income tax rate;
- Reductions in the small business corporate income tax rate;
- A low-income climate action tax credit;
- A northern and rural homeowner benefit of up to CAD 200; and
- An industrial property tax credit.

From its launch in 2008 to 2016, the carbon tax generated about CAD 7.3 billion and helped offset tax reductions of about CAD 8.9 billion (British Columbia, 2016), meaning that tax cuts and direct payments have exceeded tax revenue. A study of the distributional impacts on households suggests that the carbon tax is "highly progressive" (Beck *et al.*, 2015), showing that, through a design that incorporates revenue allocation, a carbon tax need not be regressive, as critics often contest. Each year, the Ministry of Finance of British Columbia prepares a plan for tax reductions and expenditures based on the carbon tax revenues and presents the plan to the Legislative Assembly for review and approval.

In terms of emissions, British Columbia has seen a 5.5% decrease in emissions between 2007 and 2014, despite an 8.1% increase in population and real GDP growth of 12.4% over the same period (British Columbia, 2016). Averaged across the period between 2008 and 2013, per capita emissions decreased even more markedly compared to the period from 2000 to 2007: in British Columbia, per capita emissions fell by 12.9%, compared to only a 3.7% per capita decline for the rest of Canada (Komanoff *et al.*, 2015). From when the tax took effect, fossil fuel use in British Columbia has dropped considerably relative to the rest of Canada, with computable general equilibrium modeling and econometric difference-in-difference studies suggesting that the tax accounts for a 5% to 15% decline (Murray *et al.*, 2015). Meanwhile, GDP growth in British Columbia slightly outpaced growth in the rest of the country, with a compound annual average of 1.55% per year in British Columbia compared to 1.48% outside of the province (Komanoff *et al.*, 2015).

Given its design and implementation, including its revenue neutrality, British Columbia's carbon tax is often lauded as a textbook example of a Pigovian tax (see, e.g., Murray *et al.*, 2015). It has also been studied due to the unique political circumstances that allowed a conservative government to introduce a progressive, 'green' tax reform, with sustained public support. One study, by Harrison (2013), attributes the favorable political economy to five factors: abundance of hydroelectric resources for low-carbon power generation in the province; changing political culture and increased voter interest in the issue of climate change; a right-of-center government that enjoyed trust and support within the business community; a strong personal commitment by the Premier, Gordon Campbell; and a political structure that affords substantial power to the leader of the largest party (Harrison, 2013). Tellingly, despite efforts by opposition parties to campaign against the tax, the ruling party was twice re-elected.

In 2016, the Canadian federal government announced plans for a coordinated nation-wide carbon price, which is to start at CAD 10 per ton in 2018 and rise to CAD 50 per ton by 2022. Partly in response to this impetus from Ottawa, a left-of-center government elected in British Columbia in 2017 signaled its commitment to raise the carbon tax each year by CAD 5 per metric ton of CO_2e emissions starting on 1 April 2018, and until rates reach CAD 50 per ton of CO_2e on 1 April 2021 (British Columbia, 2017). At the same time, the commitment to revenue neutrality has been loosened, with the corporate income tax reduction rescinded.

References

ACE [ASEAN Center for Energy], 2016. ASEAN Renewable Energy Policies.

ACE [ASEAN Center for Energy], 2017. The 5th ASEAN Energy Outlook. https://www.aseanenergy.org/resources/the-5th-asean-energy-outlook.

Açemoglu, D., *et al.*, 2012. The Environment and Directed Technical Change. *American Economic Review* 102(1): 131–166.

ADB [Asian Development Bank], 2015a. Fossil Fuel Subsidies in Indonesia: Trends, Impacts, and Reforms. https://www.adb.org/sites/default/files/publication/175444/fossil-fuel-subsidies-indonesia.pdf.

ADB [Asian Development Bank], 2015b. Vietnam Energy Sector Assesment, Strategy, and Road Map. https://www.adb.org/sites/default/files/institutional-document/178616/vie-energy-road-map.pdf.

ADB [Asian Development Bank], 2015c. Assessment of Power Sector Reforms in Vietnam: Country Report. Mandaluyong, Philippines.

Aguiar, A., B. Narayanan & R. McDougall, 2016. An Overview of the GTAP 9 Data Base. *Journal of Global Economic Analysis* 1(1): 181–208.

Anadón, L., E. Baker, V. Bosetti & L. Reis, 2016. Too Early to Pick Winners: Disagreement across Experts Implies the Need to Diversify R&D Investment. Milan: Fondazione Eni Enrico Mattei.

Audinet, P., B. Singh, D.T. Kexel, S. Suphachalasai, P. Makumbe & K. Mayer, 2016. Exploring a Low-Carbon Development Path for Vietnam. World Bank Group, Washington, DC. doi:10.1596/9781464807190.

Annunziata, M. & G. Bell, 2015. Powering the Future: Leading the digital transformation of the power industry. GE White Paper. https://www.res4med.org/wp-content/uploads/2017/05/digital-energy-transformation-whitepaper.pdf.

BAPPENAS [Ministry of National Development Planning], 2011. Presidential Decree 61/2011, National Action Plan to Reduce GHG emissions (RAN-GRK). http://ranradgrk.bappenas.go.id/rangrk/admincms/downloads/resources/Presidential_Regulation_No.61_Year_2011_National_Action_Plan_on_GHG_Emission_Reduction_.pdf.

Bator, F., 1958. The Anatomy of Market Failure. *The Quarterly Journal of Economics* 72(3): 351–379.

Baumol, W., 1972. On Taxation and the Control of Externalities. *The American Economic Review* 62(3): 307–322.

Baumol, W. & W. Oates, 1988. *The Theory of Environmental Policy*. 2nd ed. Cambridge: Cambridge University Press.

Bayer, B., 2018. Experience with Auctions for Wind Power in Brazil. *Renewable and Sustainable Energy Reviews* 81: 2644–2658.

Beck, M., N. Rivers, R. Wigle & H. Yonezawa, 2015. Carbon Tax and Revenue Recycling: Impacts on Households in British Columbia. *Resource and Energy Economics* 41: 40–69.

Berg, S. & J. Tschirhart, 1988. Natural Monopoly Regulation: Principles and Practices. Cambridge: Cambridge University Press.

Bertram, C. *et al.*, 2015. Carbon Lock-in through Capital Stock Inertia Associated with Weak Near-term Climate Policies. *Technological Forecasting & Social Change* 90: 62–72.

Bertram, C. *et al.*, 2015. Complementing Carbon Prices with Technology Policies to Keep Climate Targets within Reach. *Nature Climate Change* 5: 235–239.

Bhandari, D. & G. Shrimali, 2018. The Perform, Achieve and Trade Scheme in India: An Effectiveness Analysis. *Renewable and Sustainable Energy Reviews* 81: 1286–1295.

BMWiE [Bundesministerium für Wirtschaft und Energie], 2017. Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland. Berlin: Bundesministerium für Wirtschaft und Energie.

Böhringer, C., H. Koschel & U. Moslener, 2008. Efficiency Losses from Overlapping Regulation of EU Carbon Emissions, *Journal of Regulatory Economics* 33(3): 299–317.

BP, 2015. *Statistical Review of World Energy*. BP plc., London, UK.

BP, 2017. *Statistical Review of World Energy*. BP plc., London, UK.

British Columbia, 2017. B.C. Provincial Budget Tax Changes. Victoria, BC: Government of British Columbia. https://www2.gov.bc.ca/gov/content/taxes/tax-changes/budget-changes.

British Columbia, 2016. British Columbia's Carbon Tax: Carbon Pricing that Works. Victoria, BC: Government of British Columbia. https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/carbon-tax/carbon_tax_brochure_2016_final.pdf.

British Columbia, 2015. How the Carbon Tax Works. Victoria, BC: Government of British Columbia.http://www.fin.gov.bc.ca/tbs/tp/climate/A4.htm.

Buchanan, J.M. & W.C. Stubblebine, 1962. Externality, *Economica* 29(116): 371–384.

Burtraw, D. & W. Shobe, 2009. State and Local Climate Policy under a National Emissions Floor. Washington, DC: Resources for the Future.

CAA [Clean Air Act], 1963. 88th Congress, H.R.6518 (17 December 1963), as amended in 1967, 1970 and 1990, 42 U.S. Code Chapter 85 § 7401.

Cattelaens, P., 2016. Solar Energy in Vietnam. Gesellschaft für Internationale Zusammenarbeit (GIZ), Eschborn, Germany.

Campbell, S., R. Musch & L. Huynh, 2018. Renewable Energy in Vietnam. Hogan Lovells. https://www.hoganlovells.com/~/media/hogan-lovells--renewable-energy-in-vietnam-jan-2018.pdf.

Caron, J., S. Rausch & N. Winchester, 2015. Leakage from subnational climate initiatives: The case of California, *The Energy Journal* 36(2), 167–190.

CCC [Climate Change Commission], 2011. National Climate Change Action Plan 2011–2028, Office of the President of the Philippines, https://drive.google.com/file/d/0B35ePJ5EjR1GUEotajFxVl9XRDA/view?usp=sharing.

Chen, Y.-H., S. Paltsev, J. Reilly, J. Morris & M. Babiker, 2016. Long-term economic modeling for climate change assessment, *Economic Modeling* 52(B), 867–883.

Climate Change Response (Emissions Trading and Other Matters) Amendment Act 2012, Public Act 2012 No. 89, 13 November 2012.

Climate Change Response (Emissions Trading) Amendment Act 2008, Public Act 2008 No. 85, 25 September 2008.

Climate Change Response Act 2002, Public Act 2002 No. 40, 18 November 2002.

Coase, R.H., 1960. The Problem of Social Cost. *Journal of Law and Economics* 3: 1–44.

Cozzi, P., 2012. Assessing Reverse Auctions as a Policy Tool for Renewable Energy Deployment. Center for International Environment and Resource Policy (CIERP) Working Paper No. 007. Medford, MA: Tufts University.

Cramton, P., 2017. Electricity Market Design. *Oxford Review of Economic Policy* 33: 589–612.

Dales, J., 1968. Pollution, Property & Prices: An Essay in Policymaking and Economics. Toronto, ON: University of Toronto Press.

Dasgupta, S., F. van der Salm & J. Roy, 2016. Designing PAT as a Climate Policy in India: Issues Learnt from EU-ETS. In N. Ghosh, P. Mukhopadhyay, A. Shah, M. Panda (eds.), *Nature, Economy and Society* 315–328. New Delhi *et al.*: Springer.

Davis, L., A. Fuchs & P. Gertler, 2014. Cash for Coolers: Evaluating a Large-Scale Appliance Replacement Program in Mexico, *American Economic Journal: Economic Policy* 6(4), 207–238.

De Mooij, R., M. Keen & I. Parry, 2012. Fiscal Policy to Mitigate Climate Change: A Guide for Policy Makers, International Monetary Fund, Washington, DC.

del Río, P. & P. Linares, 2014. Back to the Future? Rethinking Auctions for Renewable Electricity Support. *Renewable and Sustainable Energy Reviews* 35: 42–56.

DGCC [Directorate General of Climate Change], 2015. First Biennial Update Report to the UNFCCC. Ministry of Environment and Forestry, Jakarta, Indonesia.

Di Gregorio, M., *et al.* (2017): Climate Policy Integration in the Land Use Sector: Mitigation, Adaptation and Sustainable Development Linkages, *Environmental Science & Policy* 67: 35–43.

Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC.

DNPI [Directorate General of Climate Change], 2017. Third National Communication to the UNFCCC. Ministry of Environment and Forestry, Jakarta, Indonesia.

DOT & EPA [Department of Transportation and Environmental Protection Agency], 2017. Notice of Intention to Reconsider the Final Determination of the Mid-Term Evaluation of Greenhouse Gas Emissions Standards for Model Year 2022–2025 Light Duty Vehicles of 3 March 2017 (2017) 82(54) Federal Register 14671.

EIA [Energy Information Administration], 2017. Monthly Energy Review March 2017, www.eia.gov/totalenergy/data/monthly/archive/00351703.pdf.

EIA [Energy Information Administration], 2018. Annual Energy Outlook. Washington, DC.

Eckstein, D., V. Künzel & L. Schäfer, 2017. Global Climate Risk Index 2018. Germanwatch. Bonn, Germany.

EPA [Environmental Protection Agency], 2012. Regulatory Announcement EPA-420-F-12-05, http://nepis.epa.gov/Exe/ZyPDF.cgi/P100EZ7C.PDF?Dockey=P100EZ7C.pdf.

EPCA [Energy Policy and Conservation Act], 1975. 94th Congress, S.622 (22 December 1975), Pub. L. 94-163, 89 Stat. 871, as amended by the Energy Independence and Security Act (EISA), 110th Congress, HR 6 (19 December 2007), 42 U.S. Code Chapter 152 § 17001.

Fankhauser, S., C. Hepburn & J. Park, 2010. Combining Multiple Climate Policy Instruments: How Not to Do It. *Climate Change Economics* 1(3): 209–225.

FAO [Food and Agriculture Organization], 2017. FAOSTAT: Food and Agriculture Data–Land Use Total. http://www.fao.org/faostat/en/#data/GL.

Fischer, C. & L. Preonas, 2010. Combining Policies for Renewable Energy: Is the Whole Less Than the Sum of Its Parts? *International Review of Environmental and Resource Economics* 4(1): 51–92.

Fischer, C. & R.G. Newell, 2008. Environmental and Technology Policies for Climate Mitigation. *Journal of Environmental Economics and Management* 55(2): 142–162.

Förster, S. & A. Amazo, 2016. Auctions for Renewable Energy Support in Brazil: Instruments and Lessons Learnt. AURES Report D4.1-BRA. Cologne: Ecofys.

GDE [General Directorate of Energy], 2017. Viet Nam's Power Development Plan. Ministry of Industry and Trade, Ha Noi, Viet Nam. www.energyinnovation.net.au/_literature_173538/Hnet_Vietnam_GDE.

GE, 2016. The Digital Transformation of Electricity. https://www.ge.com/digital/powering-digital-transformation-electricity.

GE, 2017. Enhance Efficiency–Reduce Emissions. http://go.digital.ge.com/DPP_for_Steam.html.

GE, 2018a. Gas Turbines–9HA. https://www.gepower.com/gas/gas-turbines/9ha.

GE, 2018b. Onshore Wind Services, GE Wind. https://www.ge.com/content/dam/gepower-renewables/global/en_US/documents/wind-services/_WindServices_Brochure.pdf.

GIZ [GIZ Energy Support Programme in Viet Nam], 2016. Highlights of the PDP 7 Revised, GIZ, http://gizenergy.org.vn/media/app/media/legal%20documents/GIZ_PDP%207%20rev_Mar%202016_Highlights_IS.pdf.

Görlach, B., 2014. Emissions Trading in the Climate Policy Mix: Understanding and Managing Interactions with Other Policy Instruments. *Energy & Environment* 25: 733–749.

Goulder, L., 2013. Markets for Pollution Allowances: What Are the (New) Lessons? *Journal of Economic Perspectives* 27: 87–102.

Goulder, L. & R. Stavins, 2011. Challenges from State-Federal Interactions in US Climate Change Policy. *American Economic Review* 101: 253–257.

Goulder, L. & I. Parry, 2008. Instrument Choice in Environmental Policy. *Review of Environmental Economics and Policy* 2: 152–174.

Government of Vietnam, 2006. National Strategic Program on Energy Saving and Effective Use. 79/2006/QD-TTg.

Government of Vietnam, 2016. National Master Plan For Power Development for the 2011–2020 Period with the Vision to 2030. Decision 428/QD-TTg.

Govindaraju, VGR C., 2017. INDC and Low-Carbon Technology Deployment Scenarios: Malaysia. In V. Anbumozhi, K. Kalirajan (Eds.), *Globalization of Low-Carbon Technologies* (pp. 115–148). doi:10.1007/978-981-10-4901-9_5.

Guiness, 2018, Most Efficient Combined Cycle Power Plant, http://www.guinnessworldrecords.com/world-records/431420-most-efficient-combined-cycle-power-plant.

Ha-duong, M., A. Truong, H.N. Nguyen, H. Anh & N. Trinh, 2016. Synthesis Report on Socio-environmental Impacts of Coal and Coal-fired Power Plants in Vietnam. Vietnam Sustainable Energy Alliance. https://hal-enpc.archives-ouvertes.fr/hal-01441680/document.

Hardin, G., 1968. The Tragedy of the Commons. *Science* 162(3859): 1243–1248.

Harrington, W. *et al*., 2004. Overview: Comparing Instrument Choices. In W. Harrington *et al.* (eds): *Choosing Environmental Policy*: 1–22. Washington, DC: Resources for the Future.

Harrison, K., 2013. The Political Economy of British Columbia's Carbon Tax. OECD Environment Working Papers No. 63. Paris: OECD Publishing.

Helm, D., 2005. Economic Instruments and Environmental Policy, *Economic & Social Review* 36: 205–228.

Hill, J.S., 2017. Third Mexican Auction Awards Enel 593 Megawatts Of Wind, Canadian Solar Awarded 367 Megawatts Solar. *CleanTechnica*, 28 Nov 2017. https://cleantechnica.com/2017/11/28/third-mexican-auction-awards-enel-593-mw-wind-canadian-solar-awarded-367-mw-solar.

Hirth, L., 2013. The Market Value of Variable Renewables: The Effect of Solar Wind Power Variability on their Relative Price, *Energy Economics* 38: 218–236.

ICCTF [The Indonesia Climate Change Trust Fund], 2018. Jakarta-Selatan, Indonesia. https://www.icctf.or.id.

ICED [Indonesian Clean Energy Development], 2016. Renewable Energy Featured in PLN's 10-Year Electricity Supply Business Plan (RUPTL) 2016–2025. http://www.iced.or.id/2016/07/renewable-energy-featured-in-plns-10-year-electricity-supply-business-plan- ruptl-2016-2025.

IEA [International Energy Agency], 2015. Energy Technology Perspectives, Paris, France.

IEA [International Energy Agency], 2016a. Emissions of CO_2, CH_4, N_2O, HFC, PFCs and SF_6 (Edition 2016). IEA CO_2 Emissions from Fuel Combustion Statistics, Paris, France.

IEA [International Energy Agency], 2016b. Reducing Emissions from Fossil-Fired Generation: Indonesia, Malaysia, and Viet Nam. IEA Insight Series 2016, Paris. France.

IEA [International Energy Agency], 2017a. World Energy Balances. IEA World Energy Statistics and Balances, Paris, France.

IEA [International Energy Agency], 2017b. World Energy Outlook, Paris, France.

IEA [International Energy Agency], 2017c. Emissions of CO_2, CH_4, N_2O, HFC, PFCs and SF_6 (Edition 2017). IEA CO_2 Emissions from Fuel Combustion Statistics, Paris, France.

IEA [International Energy Agency], 2017d. WEO-2017 Special Report: Southeast Asia Energy Outlook, Paris, France.

IEA [International Energy Agency], 2018. Perform, Achieve, Trade (PAT) Scheme, last updated 22 February. https://www.iea.org/policiesandmeasures/pams/india/name-30373-en.php.

IEA CCC [International Energy Agency Clean Coal Center], 2016. An overview of HELE technology deployment in the coal power plant fleets of China, EU, Japan and USA, CCC/273, Paris, France. https://www.iea-coal.org/an-overview-of-hele-technology-deployment-in-the-coal-power-plant-fleets-of-china-eu-japan-and-usa-ccc-273.

IEX [Indian Energy Exchange], 2018. ESCert Market Update. 18 January. https://www.iexindia.com/Uploads/NewsUpdate/18_01_2018ESCert%20Market%20Press%20Release-January%202018.pdf.

IMF [International Monetary Fund], 2017. World Economic Outlook, Washington, DC.

IPCC [Intergovernmental Panel on Climate Change], 2015. Climate Change 2014: Mitigation of Climate Change. Cambridge: Cambridge University Press.

IRENA [International Renewable Energy Agency], 2016. Renewable Energy Benefits: Measuring the Economics. Abu Dhabi: International Renewable Energy Agency (IRENA).

IRENA [International Renewable Energy Agency], and Clean Energy Ministerial (CEM), 2015. Renewable Energy Auctions: A Guide to Design. Abu Dhabi: IRENA.

IRENA [International Renewable Energy Agency], 2013. Renewable Energy Auctions in Developing Countries. Abu Dhabi: IRENA.

IRENA [International Renewable Energy Agency], 2017. Renewable Energy Prospects: Indonesia. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Mar/IRENA_REmap_Indonesia_report_2017.pdf.

Irfanoglu, I. & D. van der Mensbrugghe, 2015: Development of the Version 9 Non-CO_2 GHG Emissions Database, Global Trade Analysis Project Resource 7813, Purdue University, West Lafayette, IN. https://www.gtap.agecon.purdue.edu/resources/download/7813.pdf.

Jenkins, J.D. & V. Karplus, 2016. Carbon Pricing Under Binding Political Constraints. Helsinki: UNU-WIDER.

JCM [Joint Crediting Mechanism], 2018. https://www.jcm.go.jp/id-jp/about.

Johansen, L., 1965. Public Economics. Amsterdam: North-Holland Publishing Co.

Joskow, P.L. & R. Schmalensee, 1983. Markets for Power: An Analysis of Electric Utility Deregulation. Cambridge, MA: MIT Press.

Karplus, V. & S. Paltsev, 2012. Proposed Vehicle Fuel Economy Standards in the United States for 2017 to 2025: Impacts on the Economy, Energy, and Greenhouse Gas Emissions. *Transportation Research Record*, 2287: 132–139.

Keohane, N.O., R.L. Revesz & R.N. Stavins, 1998. The Choice of Regulatory Instruments in Environmental Policy. *Harvard Environmental Law Review* 22(2): 313–367.

Knudson, W.A., 2009. The Environment, Energy, and the Tinbergen Rule. Bulletin of Science, *Technology & Society* 29(4): 308–312.

Koch, N., G. Grosjean, S. Fuss & O. Edenhofer, 2014. Causes of the EU ETS Price Drop: Recession, CDM, Renewable Policies or A Bit of Everything? New Evidence. *Energy Policy* 73: 676–685.

Komanoff, C. & M. Gordon, 2015. British Columbia's Carbon Tax: By the Numbers. New York, NY: Carbon Tax Center. https://www.carbontax.org/wp-content/uploads/CTC_British_Columbia's_Carbon_Tax_By_The_Numbers.pdf.

Krause, F., H. Bossel & K.-F. Müller-Reißmann, 1980. Energiewende: Wachstum und Wohlstand ohne Erdöl und Uran. Berlin: S. Fischer Verlag.

Krey, V., O. Masera, G. Blanford, T. Bruckner, R. Cooke, K. Fisher-Vanden, H. Haberl, E. Hertwich, E. Kriegler, D. Mueller, S. Paltsev, L. Price, S. Schlömer, D. Ürge-Vorsatz, D. van Vuuren & T. Zwickel, 2014. Annex II: Metrics & Methodology. In: *Climate Change 2014: Mitigation of Climate Change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel & J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Krosnick, J.A. & B. MacInnis, 2013. Does the American Public Support Legislation to Reduce Greenhouse Gas Emissions? *Daedalus* 142(1): 26–39.

Krupnick, A.J., I.W.H. Parry, M.A. Walls, T. Knowles & K. Hayes, 2010. Toward a New National Energy Policy: Assessing the Options. Washington DC: Resources for the Future.

Labandeira, X. & P. Linares, 2011. Second-best Instruments for Energy and Climate Policy. In I. Galarraga, M. González-Eguino, A. Markandya (eds.), *Handbook of Sustainable Energy*: 441–451. Cheltenham: Edward Elgar.

Lanz, B. & T. Rutherford, 2016. GTAPinGAMS: Multiregional and small open economy models. *Journal of Global Economic Analysis* 1(2), 1–77.

Maurer, L. & L.A. Barroso, 2011. Electricity Auctions: An Overview of Efficient Practices. Washington D.C.: World Bank Group.

Meckling, J., N. Kelsey, E. Biber & J. Zysman, 2015. Winning Coalitions for Climate Policy: Green Industrial Policy Builds Support for Carbon Regulation. *Science* 349(6253): 1170–1171.

Mersmann, F., T. Wehnert & T. Andreeva, 2017. Implementation of Nationally Determined Contributions: Indonesia Country Report. https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2017-10-26_climate-change_24-2017_country-report-indonesia.pdf.

MIT, 2016. Utility of the Future, Massachusetts Institute of Technology, Cambridge, MA.

MIT Joint Program, 2016. *Food, Water, Energy and Climate Outlook*, MIT Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology, Cambridge, MA. https://globalchange.mit.edu/Outlook2016.

MNRE [Ministry of Natural Resources and Environment], 2017. Second Biennial Update Report to the UNFCCC. Hanoi, Viet Nam.

Mora, D., *et al.*, 2017. Auctions for Renewable Energy Support: Taming the Beast of Competitive Bidding. Final Report of the AURES Project. http://auresproject.eu/sites/aures.eu/files/media/documents/aures-finalreport.pdf.

Murray, B. & N. Rivers, 2015. British Columbia's Revenue-Neutral Carbon Tax: A Review of the Latest 'Grand Experiment' in Environmental Policy. *Energy Policy* 86: 674–83.

Nachmany, M., S. Fankhauser, J. Davidová, N. Kingsmill, T. Landesman, H. Roppongi, P. Schleifer, J. Setzer, A. Sharman, C. Singleton, J. Sundaresan & T. Townshend, 2015. Climate Change Legislation in Indonesia. http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2015/05/INDONESIA.pdf.

Nachmany, M., S. Fankhauser, J. Davidová, N. Kingsmill, T. Landesman, H. Roppongi, P. Schleifer, J. Setzer, A. Sharman, C. Stolle Singleton, J. Sundaresan & T. Townshend, 2015. Climate Change Legislation in Vietnam. Grantham Research Institute on Climate Change and the Environment. London, United Kingdom. http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2015/05/VIETNAM.pdf.

NCCS [National Climate Change Secretariat], 2012. Climate Change & Singapore: Challenges. Opportunities. Partnerships. Prime Minister's Office, Republic of Singapore, https://www.nccs.gov.sg/sites/nccs/files/NCCS-2012.pdf.

NCCS [National Climate Change Secretariat], 2018. Carbon Tax. Prime Minister's Office, Republic of Singapore.

NCSD [National Council for Sustainable Development], 2015. Climate Change Financing Framework. Royal Government of Cambodia, Phnom Penh, Kingdom of Cambodia.

NHTSA [National Highway Traffic Safety Administration], 2010. Fact Sheet: NHTSA and EPA Establish New National Program to Improve Fuel Economy and Reduce Greenhouse Gas Emissions for Passenger Cars and Light Trucks, www.nhtsa.gov/sites/nhtsa.dot.gov/files/cafe-ghg_fact_sheet.pdf.

NHTSA and EPA [National Highway Traffic Safety Administration and Environmental Protection Agency], 2016. Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles: Phase 2, Final Rule of 16 August 2016, 40 CFR Parts 9, 22, 85, 86, 600, 1033, 1036, 1037, 1039, 1042, 1043, 1065, 1066, and 1068, 49 CFR Parts 523, 534, 535, and 538 (2016) 81(206) Federal Register 73478.

NHTSA and EPA [National Highway Traffic Safety Administration and Environmental Protection Agency], 2010. Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards, Final Rule of 1 April 2010, 40 CFR Parts 85, 86, and 600 (2010) 75(88) Federal Register 25324.

OTA [Office of Technology Assessment], 1995. Environmental Policy Tools: A User's Guide. Washington, DC: Office of Technology Assessment.

Olson, M., 1968. The Logic of Collective Action: Public Goods and the Theory of Groups. Cambridge, MA.: Harvard University Press.

OECD [Organisation for Economic Co-operation and Development], 2007. Instrument Mixes for Environmental Policy. OECD Publishing, Paris.

O'Sullivan, M., D. Edler & U. Lehr, 2016. Bruttobeschäftigung durch erneuerbare Energien in Deutschland und verringerte fossile Brennstoffimporte durch erneuerbare Energien und Energieeffizienz. Berlin: Bundesministerium für Wirtschaft und Energie.

Ostrom, E., 1990. Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge: Cambridge University Press.

Pahle, M., D. Burtraw, C. Flachsland, N. Kelsey, E. Biber, J. Meckling, O. Edenhofer & J. Zysman, 2017. What Stands in the Way Becomes the Way: Sequencing in Climate Policy to Ratchet Up Stringency Over Time. Washington, DC: Resources for the Future.

Paltsev, S., V. Karplus, H. Chen, I. Karkatsouli, J. Reilly & H. Jacoby, 2015. Regulatory Control of Vehicle and Power Plant Emissions: How Effective and at What Cost? *Climate Policy* 15(4), 438–457.

PBL [PBL Netherlands Environmental Assessment Agency], 2017. PBL Climate Pledge NDC Tool, The Hague, Netherlands.

Peters, J., 2016. The GTAP-Power Data Base: Disaggregating the electricity sector in the GTAP Data Base. *Journal of Global Economic Analysis* 1(1), 209–250.

Pigou, A.C., 1920. The Economics of Welfare. London: Macmillan & Co.

Pranadi, A.D., 2018. The History and Roadmap of Power Sector Reform in Vietnam. ASEAN Centre for Energy. http://www.aseanenergy.org/blog/the-history-and-roadmap-of-power-sector-reform-in-vietnam.

Rausch, S., Karplus V., 2014. *Markets versus Regulation: The Efficiency and Distributional Impacts of U.S. Climate Policy Proposals*. MIT Joint Program on the Science and Policy of Global Change, Report 263. https://globalchange.mit.edu/publication/15897.

Renewables Now, 2018. Brazil Awards Contracts to 1 GW in A-4 Energy Auction. 4 April 2018, https://renewablesnow.com/news/brazil-awards-contracts-to-1-gw-in-a-4-energy-auction-607779.

Renewables Now, 2016. Brazil Cancels Dec 19 Wind, Solar Auction, 15 December 2016, https://renewablesnow.com/news/brazil-cancels-dec-19-wind-solar-auction-550782.

Resosudarmo, B.P., F. Ardiansyah & L. Napitupulu, 2013. The Dynamics of Climate Change Governance in Indonesia: Climate Governance in the Developing World. Cambridge: Polity.

RGC [Royal Government of Cambodia], 2017. Cambodia's Nationally Determined Contribution. Phnom Penh, Kingdom of Cambodia.

Sahoo, N., P. Mohapatra & B. Mahanty, 2018. Examining the Process of Normalising the Energy-efficiency Targets for Coal- based Thermal Power Sector in India. *Renewable and Sustainable Energy Reviews* 81: 342–352.

Seto, K.C., *et al.*, 2016. Carbon Lock-In: Types, Causes, and Policy Implications. *Annual Review of Environment and Resources* 41: 425–452.

Singh, A, N. Winchester & V. Karplus, 2018. *Evaluating India's climate targets: the implications of economy-wide and sector specific policies*. MIT Joint Program on the Science and Policy of Global Change, Report 127. https://globalchange.mit.edu/sites/default/files/MITJPSPGC_Rpt327.pdf.

Singh, N., 2013. Creating Market Support for Energy Efficiency: India's Perform, Achieve and Trade Scheme. Washington, DC: Climate & Development Knowledge Network. http://cdkn.org/wp-content/uploads/2013/01/India-PAT_InsideStory.pdf.

Sterner, T., 2003. Policy Instruments for Environmental and Natural Resource Management. Washington, DC: Resources for the Future.

Stigler, G.J., 1971. The Theory of Economic Regulation. *Bell Journal of Economics and Management Science* 2(1): 3–21.

Sue Wing, I., 2004. *Computable General Equilibrium Models and Their Use in Economy-Wide Policy Analysis*. MIT Joint Program Technical Note #6. http://globalchange.mit.edu/publication/13808.

Thailand Ministry of Energy, 2015. Thailand Power Development Plan 2015–2036, Energy Policy and Planning Office, http://www2.eppo.go.th/power/PDP2015/PDP2015_Eng.pdf.

Thomas, K., 2016. Vietnam eyes 2023 start date for LNG imports. *LNG World Shipping*, 9 November 2016. http://www.lngworldshipping.com/news/view,vietnam-eyes-2023-start-date-for-lng-imports_45354.htm.

Tinbergen, J., 1952. On the Theory of Economic Policy. Amsterdam: North Holland Publishing Co.

Tongsopit, S., *et al.,* 2017. Designing Renewable Energy Incentives and Auctions: Lessons for ASEAN. U.S. Agency for International Development.

UN [United Nations], 2015. Paris Agreement: http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf.

UN [United Nations], 2017. 2017 Revision of World Population Prospects. United Nations Populations Division, Washington, DC.

UNDP [United Nations Development Program], 2016. Greening the Power Mix. Policies for Expanding Solar Photovoltaic Electricity in Viet Nam. New York, NY.

UNEP [United Nations Environment Program], 2017. The Emissions Gap Report 2017.

UNFCCC [United Nations Framework Convention on Climate Change], 2017a. Land Use and Climate Change. http://unfccc.int/land_use_and_climate_change/items/8792.php.

UNFCCC [United Nations Framework Convention on Climate Change], 2017b. National Reports. https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/national-communications-and-biennial-update-reports-non-annex-i-parties/national-communication-submissions-from-non-annex-i-parties.

USAID, 2017. Designing Renewable Energy Incentives and Auctions: Lessons for ASEAN. https://www.ecofys.com/files/files/re-incentivesreport-20170904-final.pdf.

Unruh, G.C., 2000. Understanding Carbon Lock-In. *Energy Policy* 28(12): 817–830.

Vandyck, T., K. Keramidas, B. Saveyn, A. Kitous & Z. Vrontisi, 2016. A global stocktake of the Paris pledges: Implications for energy systems and economy. *Global Environmental Change* 41: 46–63.

VEA [Vietnam Environment Administration], 2016. Vietnam will eliminate fossil fuel subsidies by 2020. 13 January 2016. http://vea.gov.vn/en/news/news/Pages/Vietnam-will-eliminate-fossil-fuel-subsidies-by-2020.aspx.

VNEEP [Vietnam National Energy Efficiency Programme], 2016. Vietnam Ranked Fourth in the World for Clean Development Mechanism Projects Quantity. Vietnam Ministry of Industry and Trade, http://vneec.gov.vn/tin-tuc/projects/t24106/vietnam-ranked-fourth-in-the-world-for-clean-development-mechanism-projects-quantity.html.

Wagner, G. *et al*., 2015. Energy Policy: Push Renewables to Spur Carbon Pricing. *Nature* 525: 27–29.

Weitzman, M.L., 2009. The Extreme Uncertainty of Extreme Climate Change: An Overview and Some Implications. Cambridge, MA: Harvard University, Unpublished manuscript. https://pdfs.semanticscholar.org/ca75/48f6d3daa1ab6ef1f05bdc8bcd25b4edfbf0.pdf.

Weitzman, M.L., 1974. Prices vs. Quantities. *The Review of Economic Studies* 41(4): 477–491.

Winchester, N., S. Paltsev, J. Morris & J. Reilly, 2010. Costs of mitigating climate change in the United States. *Annual Review of Resource Economics* 2: 257–273.

Winchester, N. & J. Relly, 2018. The economic, energy, and emissions impacts of climate Policy in South Korea. MIT Joint Program on the Science and Policy of Global Change Report 328. https://globalchange.mit.edu/sites/default/files/MITJPSPGC_Rpt328.pdf.

World Bank, 2014. Myanmar: Towards Universal Access to Electricity by 2030. https://www.iea.org/media/pams/myanmar/2014_MyanmarNEP_NationalElectricityProject_WBpresenation10012014.pdf.

World Bank, 2017. Fourth Power Sector Reform Development Policy Operation: Project Information Document (PID), Report No. 114955. http://documents.worldbank.org/curated/en/137681494560218182/pdf/114955-PGID-P157722-Appraisal-Box402908B-PUBLIC-Disclosed-5-11-2017.pdf.

Appendix A. Summary of ASEAN countries' pledges

Official Pledges			Country Estimates			MIT Estimates		
Stringency	Type	Description	2030 BAU ($MtCO_2e$)	Reduction ($MtCO_2e$)	2030 Target Emissions ($MtCO_2e$)	2030 BAU ($MtCO_2e$)	Absolute Reduction ($MtCO_2e$)	% Reduction in 2030 (Rel. to BAU)
BRUNEI								
Unconditional	Total emissions	None	--	--	--	14	4	26%
	Energy intensity of GDP	45% reduction in 2035 relative to 2005						
	Energy consumption	63% reduction in 2035 relative to BAU						
	Renewables	10% share in total generation						
	Transport emissions	40% reduction in CO_2 from morning peak hours vehicle use in 2035 relative to BAU						
	Forestry	55% of total land area as forest reserve						
Conditional	Total emissions	None	--	--	--	14	4	26%
CAMBODIA								
Unconditional	Total emissions	None	--	--	--	15	0	0%
Conditional	Total emissions	27% reduction in 2030 relative to BAU	11.6	3.1	--	15	4	27%
	Energy emissions	16% reduction in 2030 relative to BAU		1.8				
	Industry emissions	7% reduction in 2030 relative to BAU		727				
	Transport emissions	3% reduction in 2030 relative to BAU		390				
	Other emissions	1% reduction in 2030 relative to BAU		155				
	Forestry	60% of total land area as forest reserve	(7.897)	4.7 tCO_2-eq/ ha/yr				
INDONESIA								
Unconditional (w/ forestry)	Total emissions	29% reduction in 2030 relative to BAU	2869	834	2034	--	--	--
	Energy emissions	19% reduction in 2030 relative to BAU	1669	314	1355			
	Agriculture emissions	8% reduction in 2030 relative to BAU	119.66	9	110.39			
	Waste emissions	4% reduction in 2030 relative to BAU	296	11	285			
	Industry emissions	4% reduction in 2030 relative to BAU	69.6	2.75	66.85			
	Forestry emissions	70% reduction in 2030 relative to BAU	714	497	217			
	Total emissions	26% reduction in 2020 relative to BAU						
Conditional (w/forestry)	Total emissions	41% (38%) reduction in 2030 relative to BAU	2869	1081	1787	--	--	--
	Energy emissions	24% reduction in 2030 relative to BAU	1669	398	1271			
	Agriculture emissions	3% reduction in 2030 relative to BAU	119.66	4	115.86			
	Waste emissions	9% reduction in 2030 relative to BAU	296	26	270			
	Industry emissions	5% reduction in 2030 relative to BAU	69.6	3.25	66.85			
	Forestry emissions	91% reduction in 2030 relative to BAU	714	650	64			
Unconditional	Total emissions	16% reduction in 2030 relative to BAU	2155	337	1817	1,450	232	16%
	Energy emissions	19% reduction in 2030 relative to BAU	1669	314	1355			
	Agriculture emissions	8% reduction in 2030 relative to BAU	119.66	9	110.39			
	Waste emissions	4% reduction in 2030 relative to BAU	296	11	285			
	Industry emissions	4% reduction in 2030 relative to BAU	69.6	2.75	66.85			
Conditional	Total emissions	20% reduction in 2030 relative to BAU	2155	431	1723	1,450	290	20%
	Energy emissions	24% reduction in 2030 relative to BAU	1669	398	1271			
	Agriculture emissions	3% reduction in 2030 relative to BAU	119.66	4	115.86			
	Waste emissions	9% reduction in 2030 relative to BAU	296	26	270			
	Industry emissions	5% reduction in 2030 relative to BAU	69.6	3.25	66.85			
	Forestry emissions	91% reduction in 2030 relative to BAU	714	650	64			

Official Pledges			Country Estimates			MIT Estimates		
Stringency	Type	Description	2030 BAU ($MtCO_2e$)	Reduction ($MtCO_2e$)	2030 Target Emissions ($MtCO_2e$)	2030 BAU ($MtCO_2e$)	Absolute Reduction ($MtCO_2e$)	% Reduction in 2030 (Rel. to BAU)
LAO PDR								
Unconditional	Total emissions	None	--	--	--	23	0	0%
Conditional	Total emissions	None	--	--	--	23	1	5%
	Renewables	30% of energy consumed comes from non-hydro by 2025		1,468 by 2025				
	Renewables	5,500 MW of hydropower by 2020 and and additional 20,000 MW after 2020 (85% exported to Thailand and Vietnam)		16.284 per year				
	Forestry	70% of total land area as forest reserve		60-69 from 2020 on				
	Other	90% rural electrification by 2020, road network development, increased use of public transport		254 $ktCO_2$-e/ pa				
MALAYSIA								
Unconditional	Total emissions	None	--	--	--	544	5	1%
	Emission intensity of GDP	45% reduction in emission intensity of GDP in 2030 relative to 2005						
Conditional	Total emissions	None	--	--	--	544	88	16%
	Emission intensity of GDP	35% reduction in emission intensity of GDP in 2030 relative to 2005						
MYANMAR								
Unconditional	Total emissions	None	--	--	--	73	0	0%
Conditional	Total emissions	None	--	--	--	73	3	4%
	Renewables	9.4 GW hydro capacity by 2030						
	Renewables	30% of rural electricity from renewables excluding large hydro by 2030						
	Forestry	30% of total land area as forest reserve						
	Land	10% of total land area as “Protected Area Systems”						
	Other	260,000 energy efficient cook stoves distributed by 2031						
	Other	20% of “electricity savings potential” by 2030						
PHILIPPINES								
Unconditional	Total emissions	None	--	--	--	293	0	0%
Conditional	Total emissions	70% reduction in 2030 relative to BAU	--	--	--	293	205	70%
SINGAPORE								
Unconditional	Total emissions	None	--	--	--	51	(14)	(26%)
	Emission intensity of GDP	36% reduction in 2030 relative to 2005						
Conditional	Total emissions	None	--	--	--	51	(14)	(26%)
THAILAND								
Unconditional	Total emissions	20% reduction in 2030 relative to BAU	555	--	--	645	129	20%
Conditional	Total emissions	25% reduction in 2030 relative to BAU	555	--	--	645	161	25%
VIETNAM								
Unconditional	Total emissions	8% reduction in 2030 relative to BAU	787.4	--	--	571	46	8%
	Emission intensity of GDP	20% reduction in 2030 relative to 2010						
	Forestry	45% of total land area as forest cover						
Conditional	Total emissions	25% reduction in 2030 relative to BAU	787.4	--	--	571	143	25%
	Emission intensity of GDP	30% reduction in 2030 relative to 2010						

Appendix B. Methodology

B.1. Projections

Baseline Scenario

1. **Project total primary energy supply (TPES)**
    a. Use historical TPES of GDP data (2000–2015) to project energy intensity out to 2030
    b. Use historical and projected GDP data (2000–2022) from IMF (2017) to project GDP out to 2030, adopting a 0.1 percentage point annual decrease in GDP growth.
    c. Multiply energy intensity and GDP to estimate total TPES out to 2030.
    d. Determine future TPES by fuel assuming the same fuel shares as in 2015.
2. **Use TPES projections to estimate electricity generation**
    a. Calculate the ratio of generation to TPES by fuel (GWh/ktoe) in 2015.
    b. Project forward the generation-to-TPES ratio to 2030. Assume a 0.05% annual increase in the ratio for coal and natural gas and a constant ratio for other fuels.
    c. Apply the generation-to-TPES ratio to energy supply by fuel to estimate electricity generation by fuel out to 2030. Total electricity generation is the sum of generation by fuel (GWh).
3. **Use TPES projections to estimate energy sector CO_2 emissions**
    a. Apply carbon coefficients to TPES of coal, oil, and natural gas from 2000 to 2030 (0.00396 $MtCO_2$/ktoe coal, 0.00307 $MtCO_2$/ktoe oil, 0.00235 $MtCO_2$/ktoe natural gas).
4. **Use country-reported historical emissions to estimate energy sector CH_4 and N_2O emissions**
    a. Determine energy sector emissions of CH_4 and N_2O using the country's most recent National Communication or Biennial Update Report to the UNFCCC.
    b. Project forward energy CH_4 and N_2O from the last recorded year of inventory to 2030 using the average annual growth rate of natural gas production according to the 2016 IEA Energy Outlook (-0.38% in Indonesia, -0.77% in other ASEAN countries)
5. **Use country-reported historical emissions to estimate non-energy sector GHG emissions.**
    a. Determine industry, agriculture, and waste sector emissions of CO_2, CH_4, N_2O, HFC, PFC, and SF_6 using the country's most recent National Communication or Biennial Update Report to the UNFCCC.
    b. Project forward non-energy sector CH_4 and N_2O from the last recorded year of inventory to 2030 using the average annual growth rate of historical and projected GDP data (2000–2022).
    c. Project forward non-energy sector CO_2 and F gases from the last recorded year of inventory to 2030 using the historical and projected annual growth rate of population.
6. **Note that LUCUCF emissions are excluded from MIT estimates and any illustrated country-reported BAU estimates**

Policy Emission Targets

1. **Determine country-level NDC targets.**
    a. Apply conditional and unconditional goals to Baseline scenario emissions, emission intensity, or energy intensity projections. Modeled targets are summarized in Table 2.1.
2. **Determine regional NDC targets.**
    a. Aggregate country-level conditional and unconditional targets to the ASEAN region.
    b. For the unconditional ASEAN target, assume Baseline scenario emissions for countries without an unconditional target. For the conditional ASEAN target, assume the unconditionally targeted emissions for countries without a conditional target.
    c. For countries with policy targets yielding greater emissions in 2030 than in the Baseline scenario, record no contribution to targeted emission reductions in the ASEAN region.

B.2. Country-specific adjustments

1. **Brunei Darussalam**
   a. Extend Baseline scenario projections to 2035. Approximate a 2030 emission target in line with the official 2035 targets.
   b. Estimate emissions for the year 2000 using country-reported emissions for 2010 and IEA-reported emissions for 2000 and 2010.
2. **Cambodia**
   a. Consider energy sector emissions only.
3. **Indonesia**
   a. Achieve NDC-specified fuel shares in TPES in the Baseline scenario in 2025: 30% coal, 25% oil, 22% natural gas, and 23% renewables (modeled as 17% bioenergy, 0.4% hydro, and 5.3% other renewables)
   b. Maintain 2025 fuel shares until 2030
   c. Apply a 0.33% annual decrease in future energy CO_2 and N_2O emissions based on projections in the 2016 IEA Energy Outlook for natural gas production in Indonesia (versus a 0.77% annual decrease in other ASEAN countries).
   d. Recalculate policy targets as a 16% (20% conditional) from 2030 Baseline emissions rather than 38% (41% conditional) to exclude LULUCF emissions reported in the NDC.
4. **Lao PDR**
   a. No historical data available from the IEA. Instead, use historical TPES, GDP, and energy sector GHG emissions provided by ACE for the year 2005 to 2014.
   b. Consider only emissions from combustion based on availability of data.
5. **Myanmar**
   a. Consider an alternative Baseline scenario based on 2030 electricity generation capacities specified in ACE (2017): 7.940 GW coal, 4.758 GW natural gas, 8.896 GW hydro, and 2.000 GW other renewables.
   b. Assume generation capacity factors of 55% for fossil fuels, 20% for hydro, and 30% for other renewables.
6. **Philippines**
7. **Singapore**
   a. Adopt a lower average annual GDP growth for 2023–2030 to align policy emission targets with country-reported estimates.
   b. Adjust a calculation of CO_2 emissions from oil. To exclude non-combusted feedstocks that enter the refinery process, we remove 7000 ktoe of oil from the emission calculations related to oil. IEA (2017a) reports that non-energy use in chemical/petrochemical category in Singapore was 6600 ktoe in 2007, reduced in the following years, and recently recovered to 6700 ktoe in 2016-2017. We approximate feedstock use by 7000 ktoe assuming future stability in Singapore's oil refining.
   c. Use growth rate for energy intensity of GDP based on the time period 2009 to 2015 to mitigate the volatility in Singapore's economic performance during the recession of 2008–2009.
8. **Thailand**
9. **Vietnam**
   a. For electricity generation, set Vietnam's Baseline scenario hydro and biofuel generation to 89 TWh and 32 TWh respectively in 2030 in accordance with the country's Revised Power Development Plan VII.

b. Consider and alternative Baseline scenario with fuel-specific generation outputs for 2020, 2025, and 2030 in accordance with the country's Revised Power Development Plan VII.

c. Exclude non-combustion industrial emissions from the Baseline trajectories.

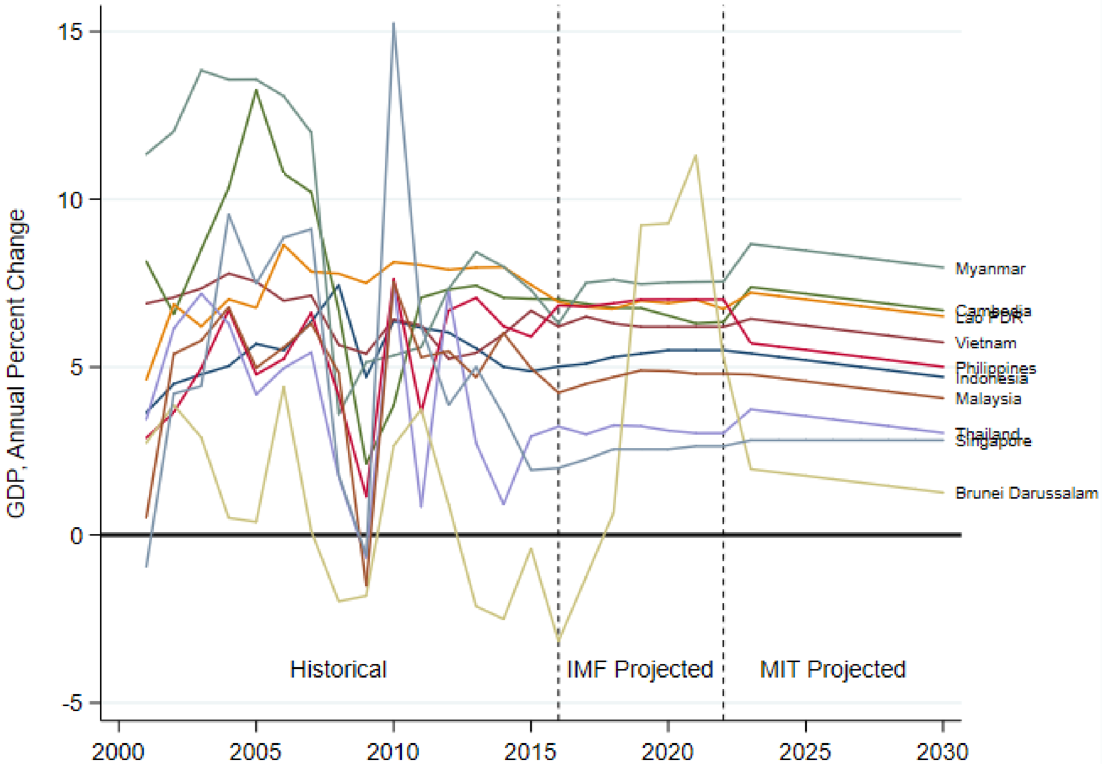

Figure B.1. ASEAN's GDP historic real growth rates (2000–2016), IMF short-term projections (2017–2022) and our assumptions for long-term growth rates (2023–2030).

Appendix C. Energy and emission intensity

Brunei Darussalam

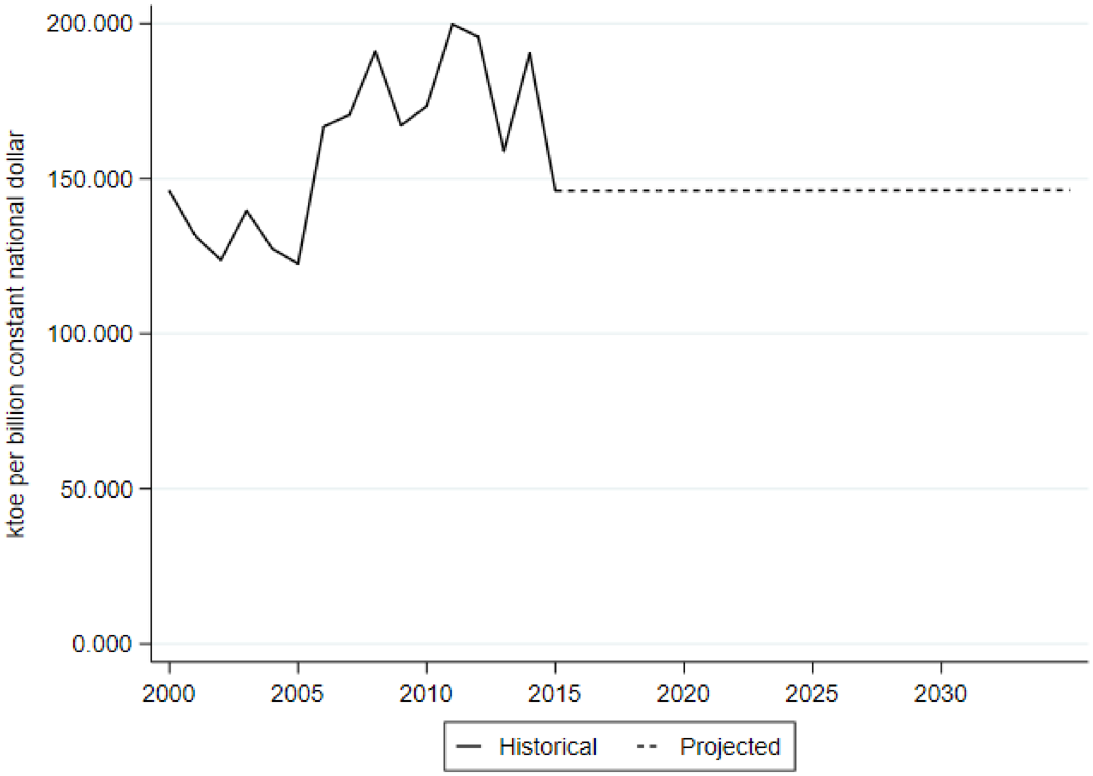

Figure C.1. Energy intensity of GDP in Brunei Darussalam

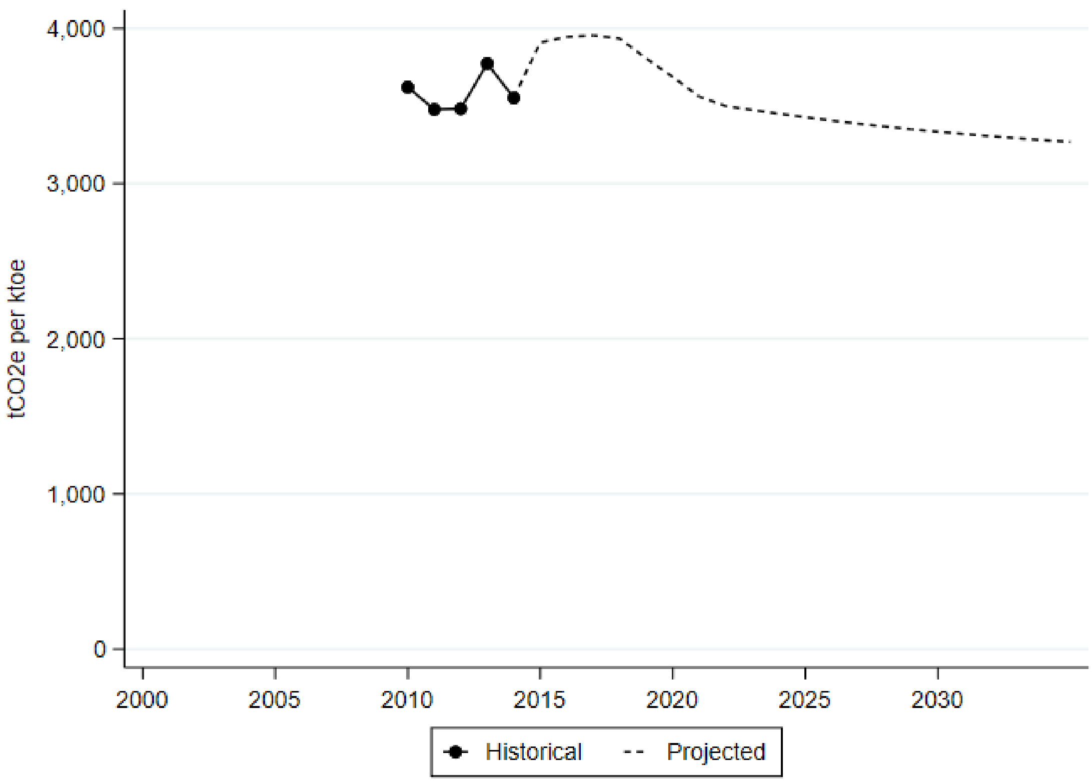

Figure C.2. Emission intensity of TPES in Brunei Darussalam

Cambodia

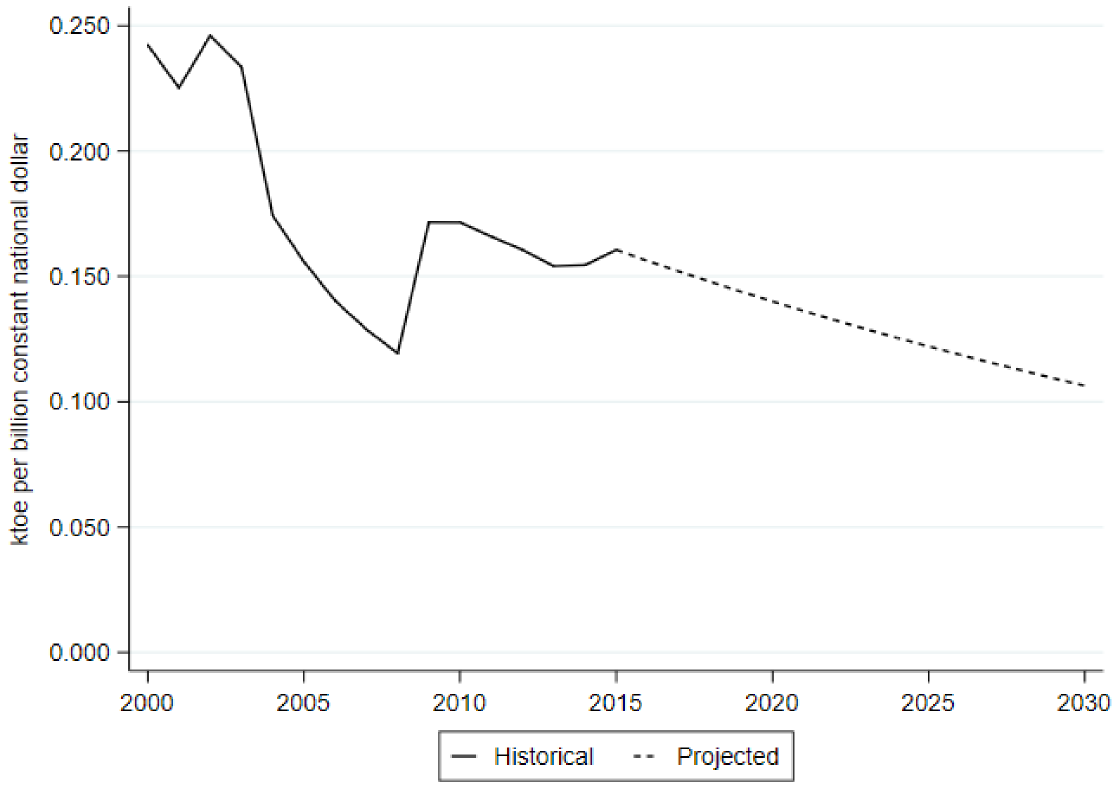

Figure C.3. Energy intensity of GDP in Cambodia

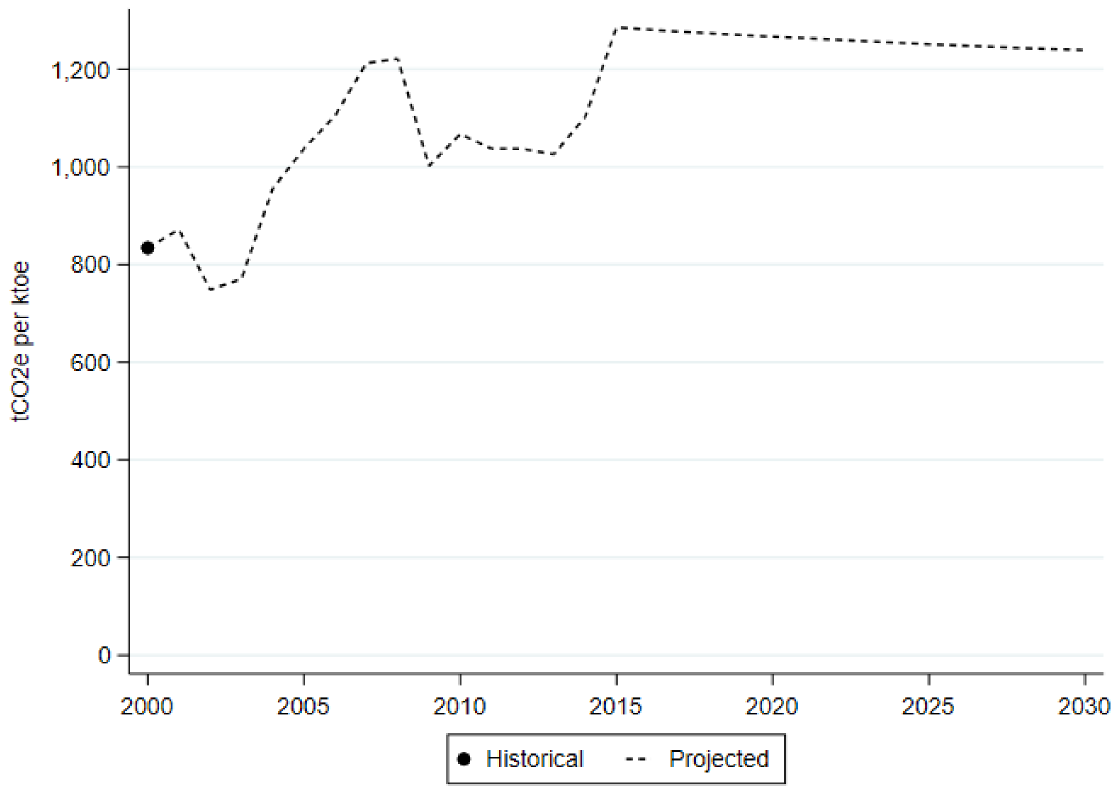

Figure C.4. Emission intensity of TPES in Cambodia

Indonesia

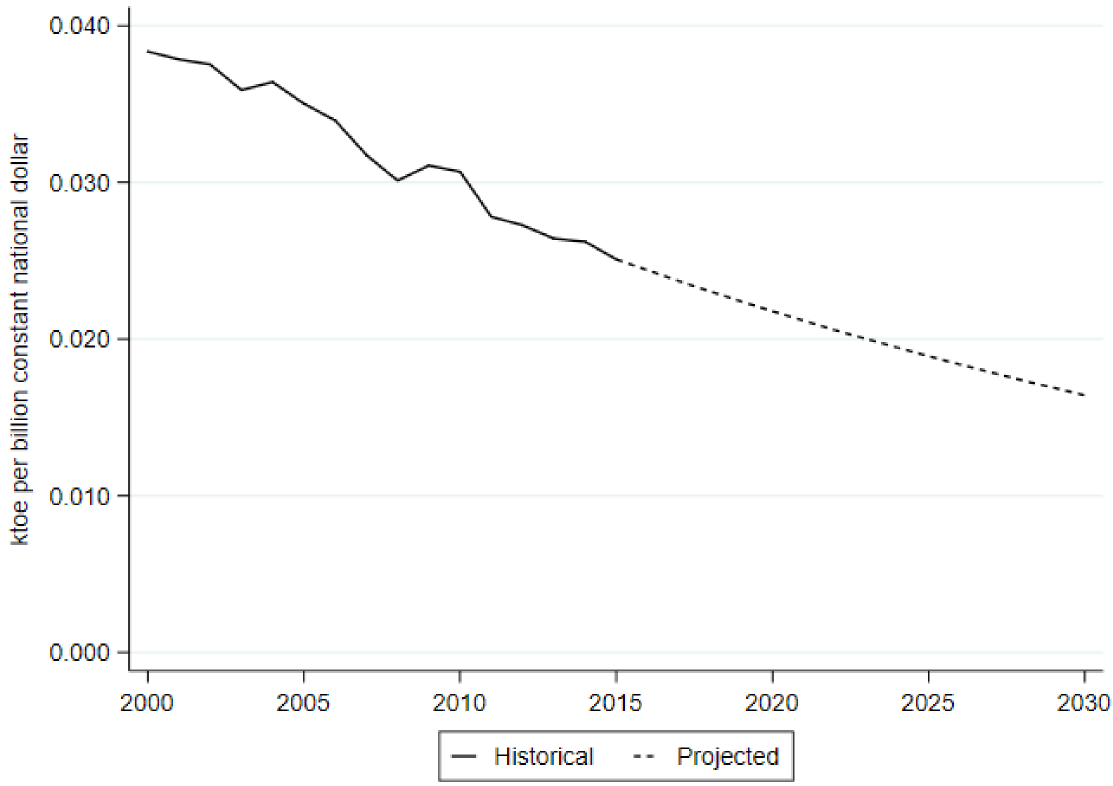

Figure C.5. Energy intensity of GDP in Indonesia

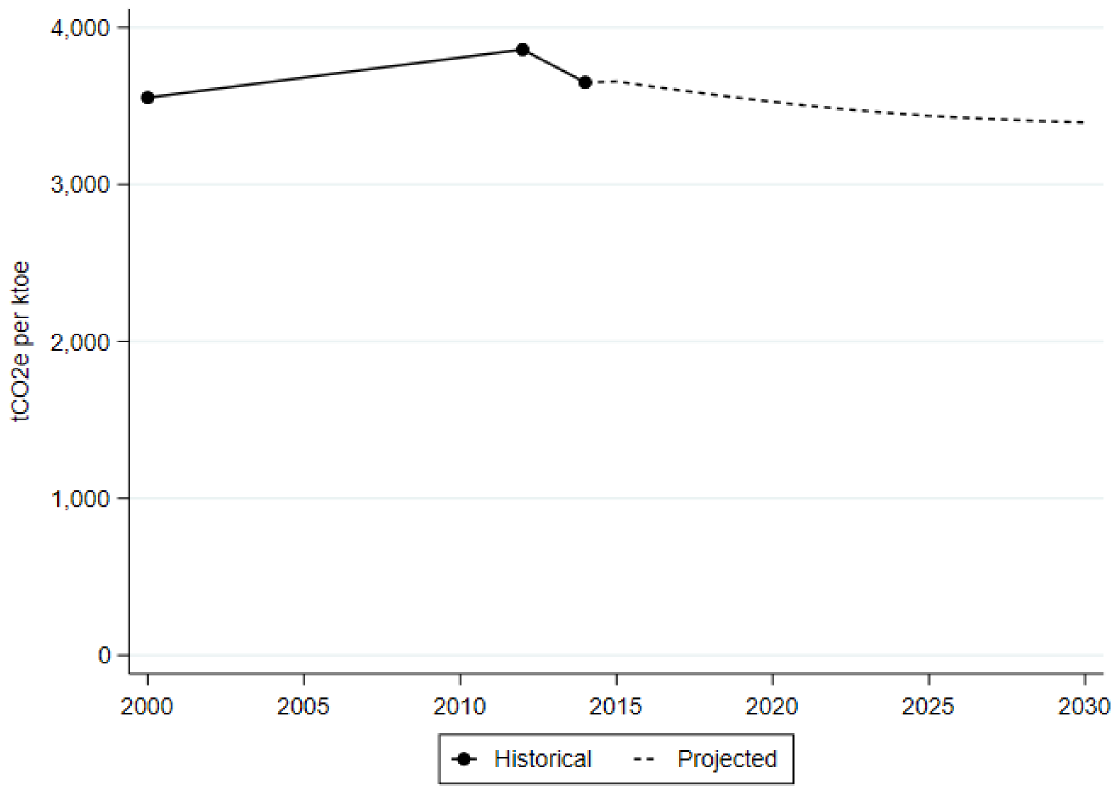

Figure C.6. Emission intensity of TPES in Indonesia

Lao PDR

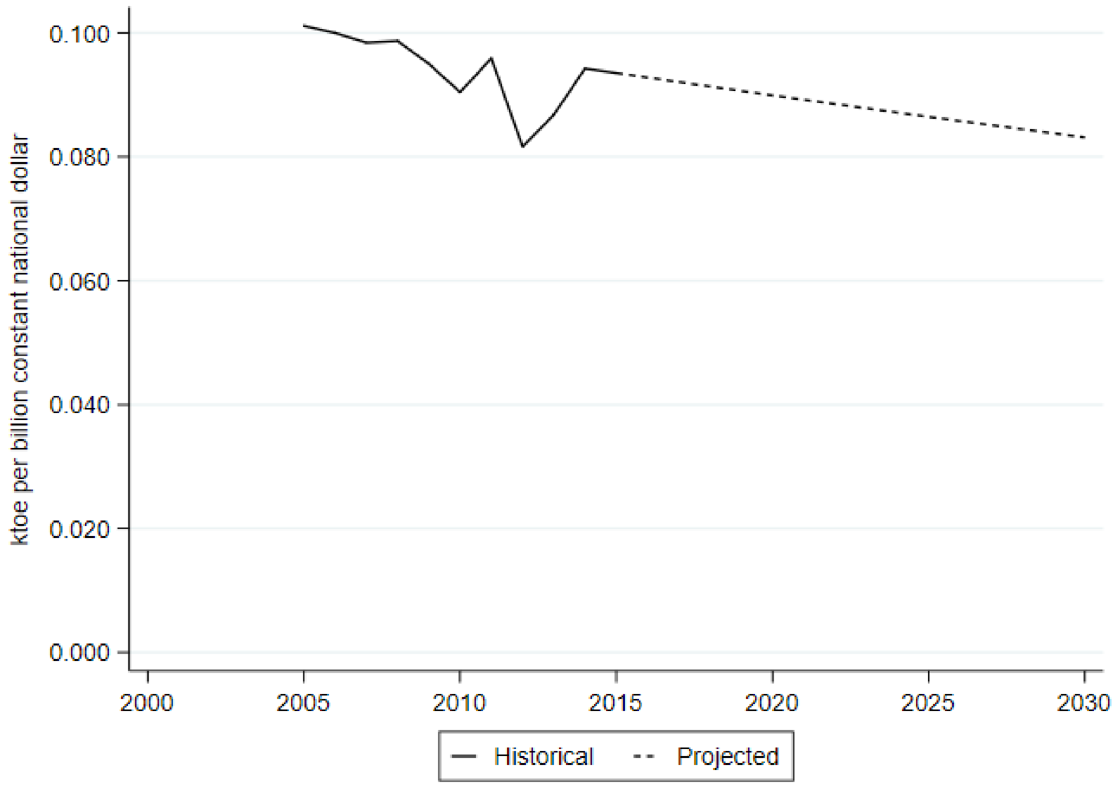

Figure C.7 Energy intensity of GDP in Lao PDR

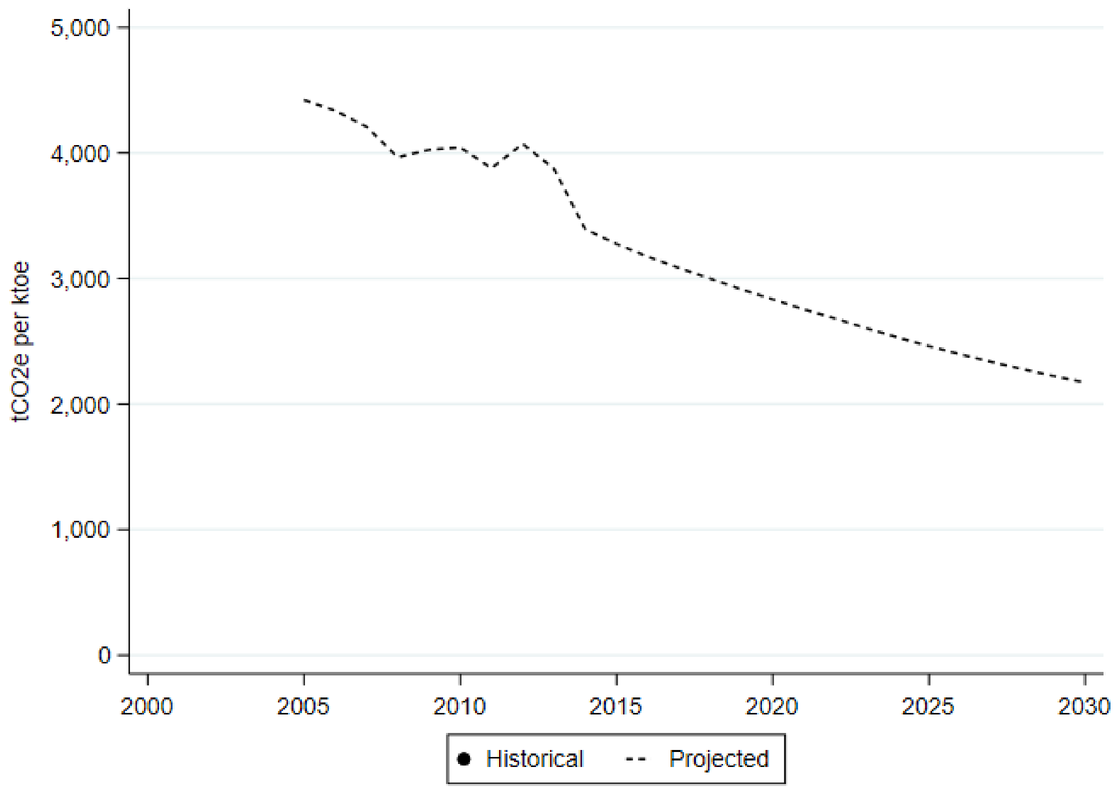

Figure C.8. Emission intensity of TPES in Lao PDR

Malaysia

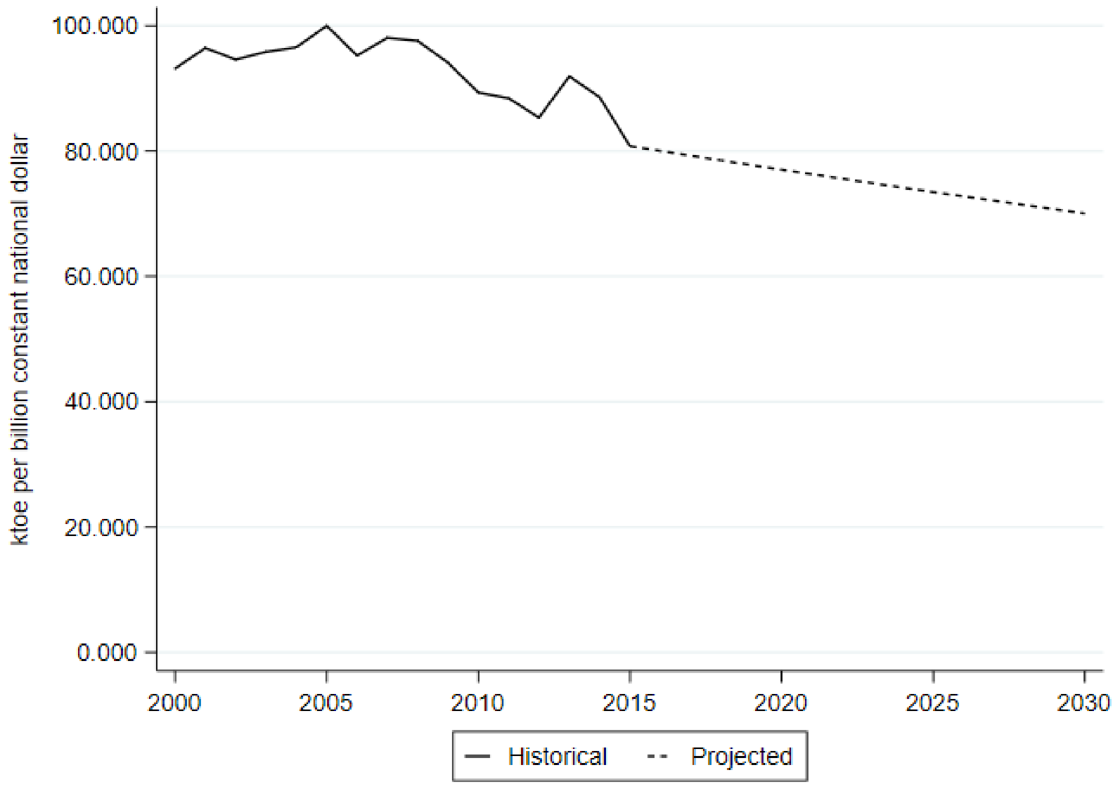

Figure C.9. Energy intensity of GDP in Malaysia

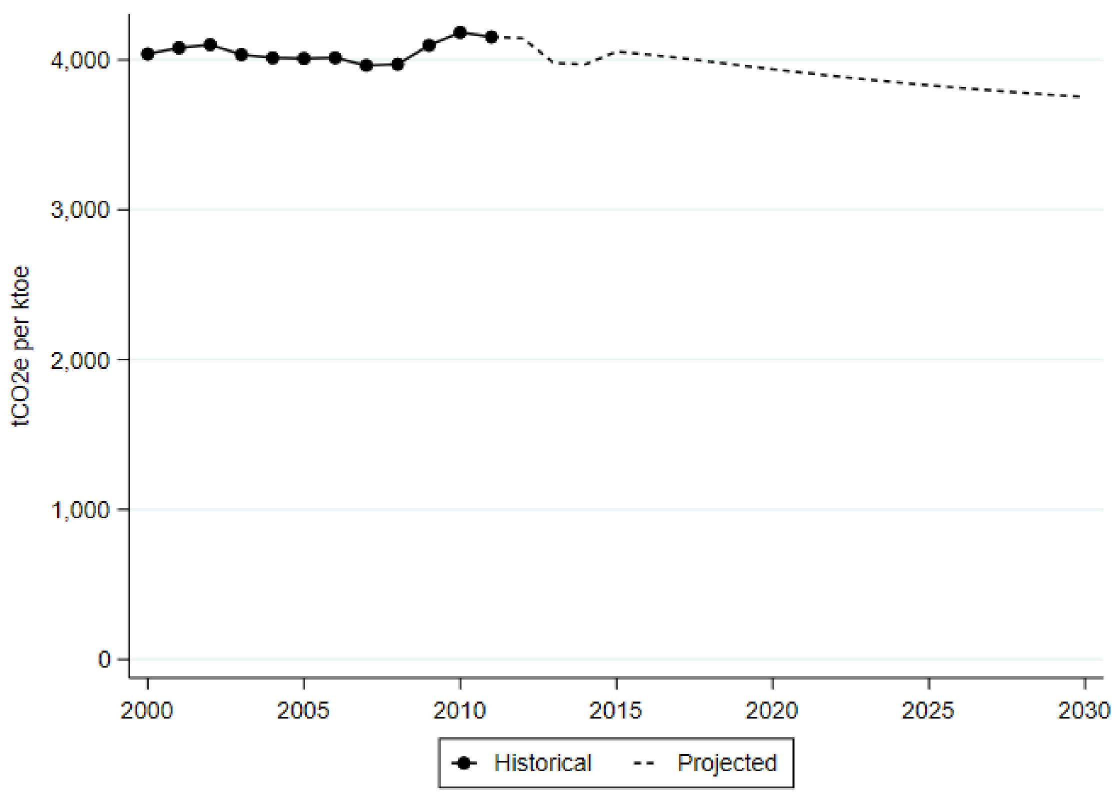

Figure C.10. Emission intensity of TPES in Malaysia

Myanmar

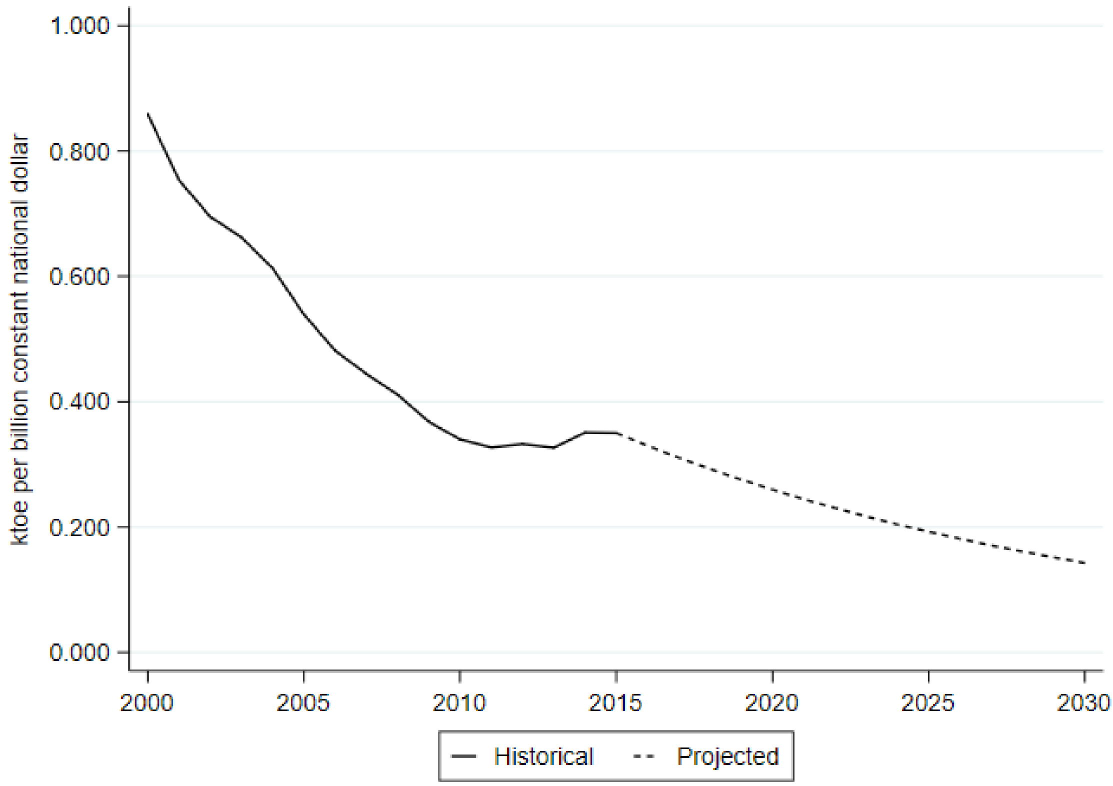

Figure C.11. Energy intensity of GDP in Myanmar

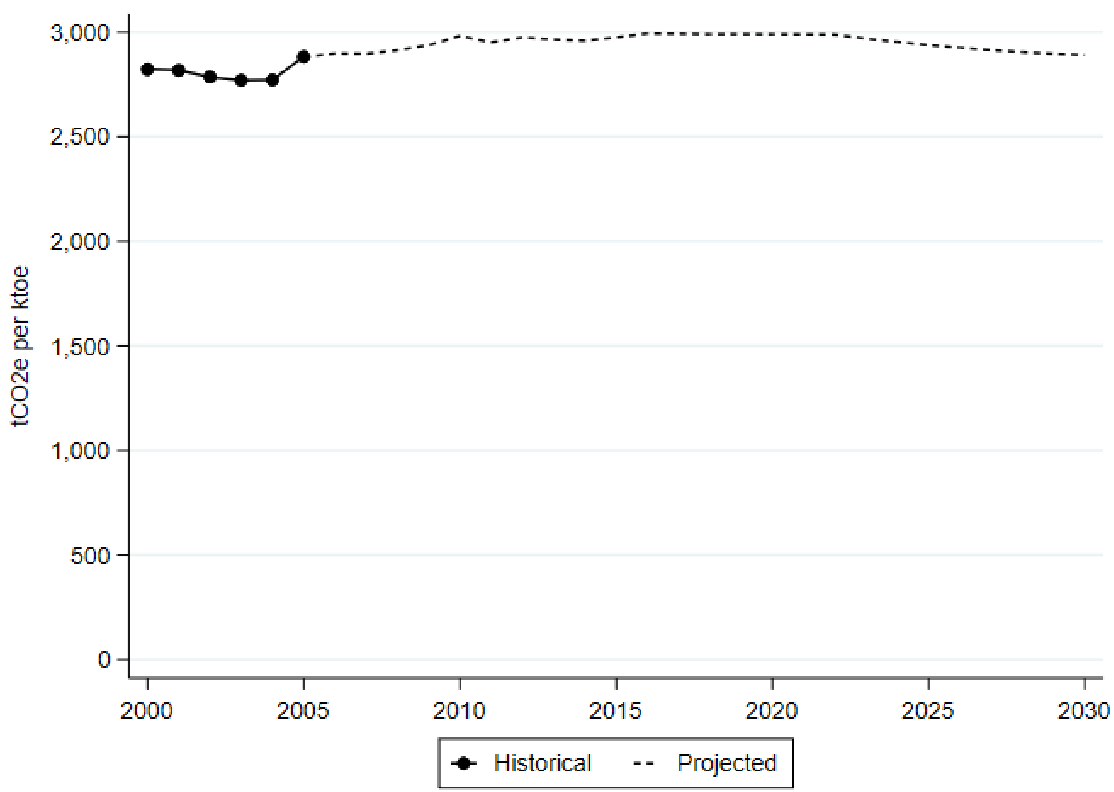

Figure C.12. Emission intensity of TPES in Myanmar

Philippines

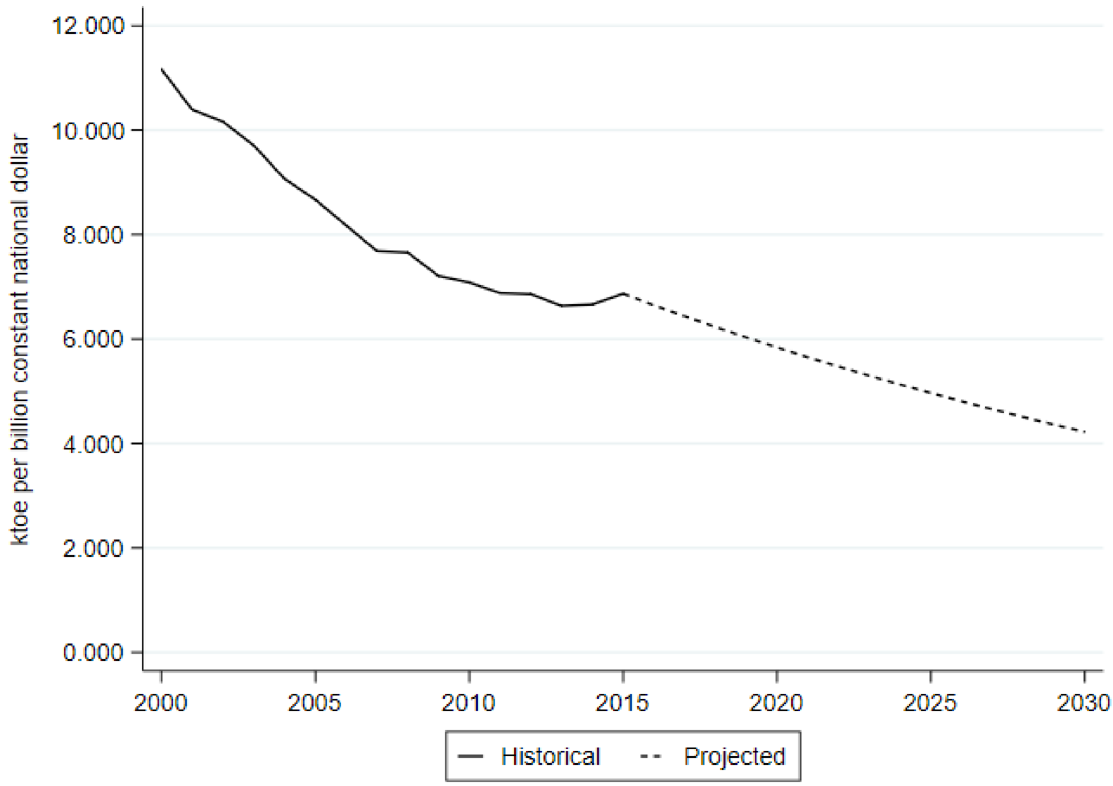

Figure C.13. Energy intensity of GDP in Philippines

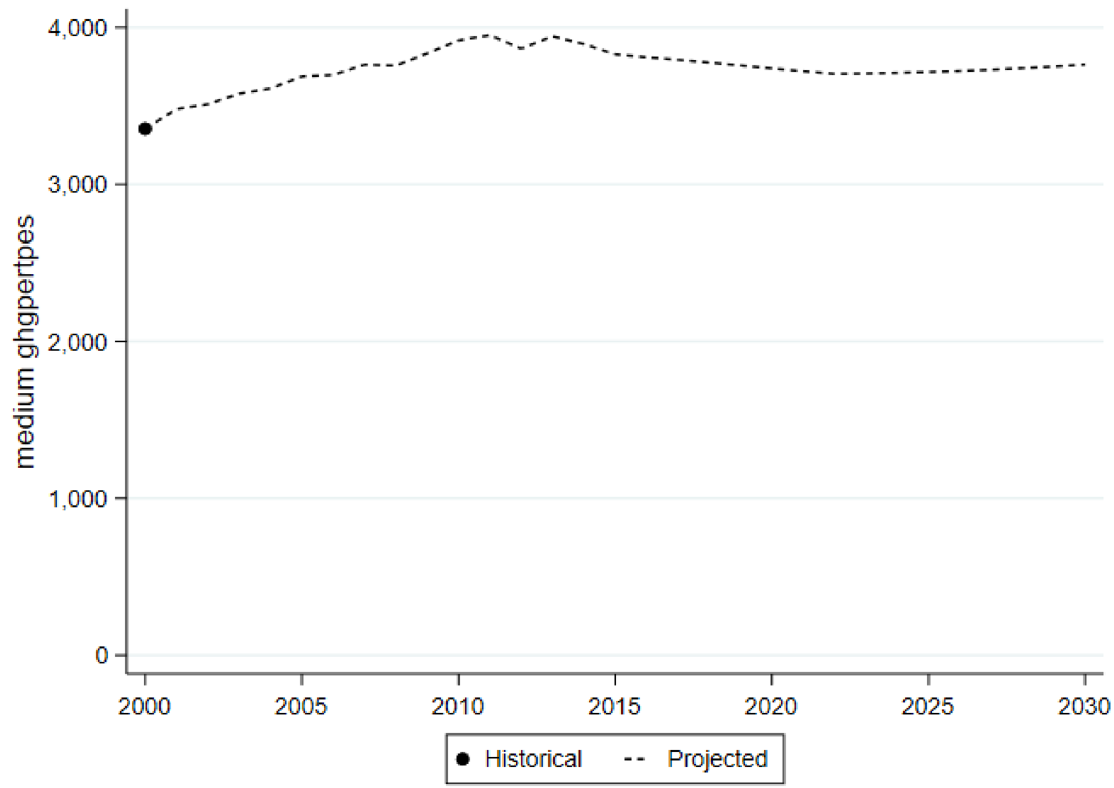

Figure C.14. Emission intensity of TPES in Philippines

Singapore

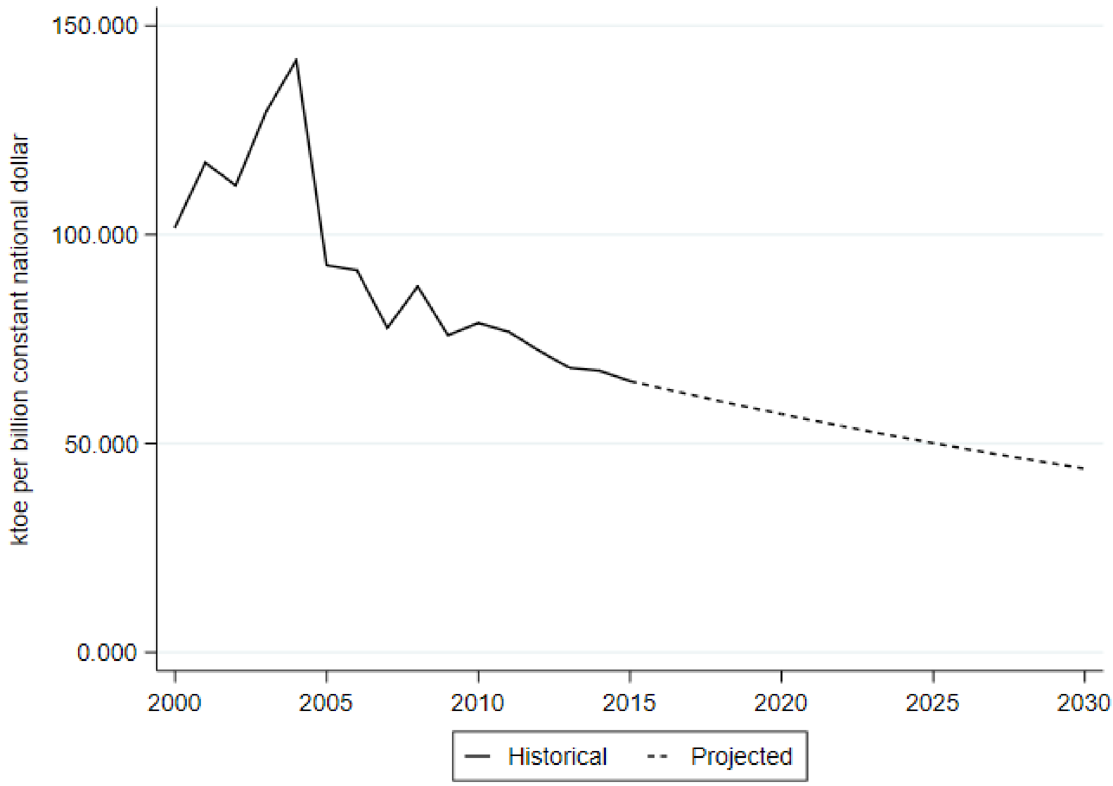

Figure C.15. Energy intensity of GDP in Singapore

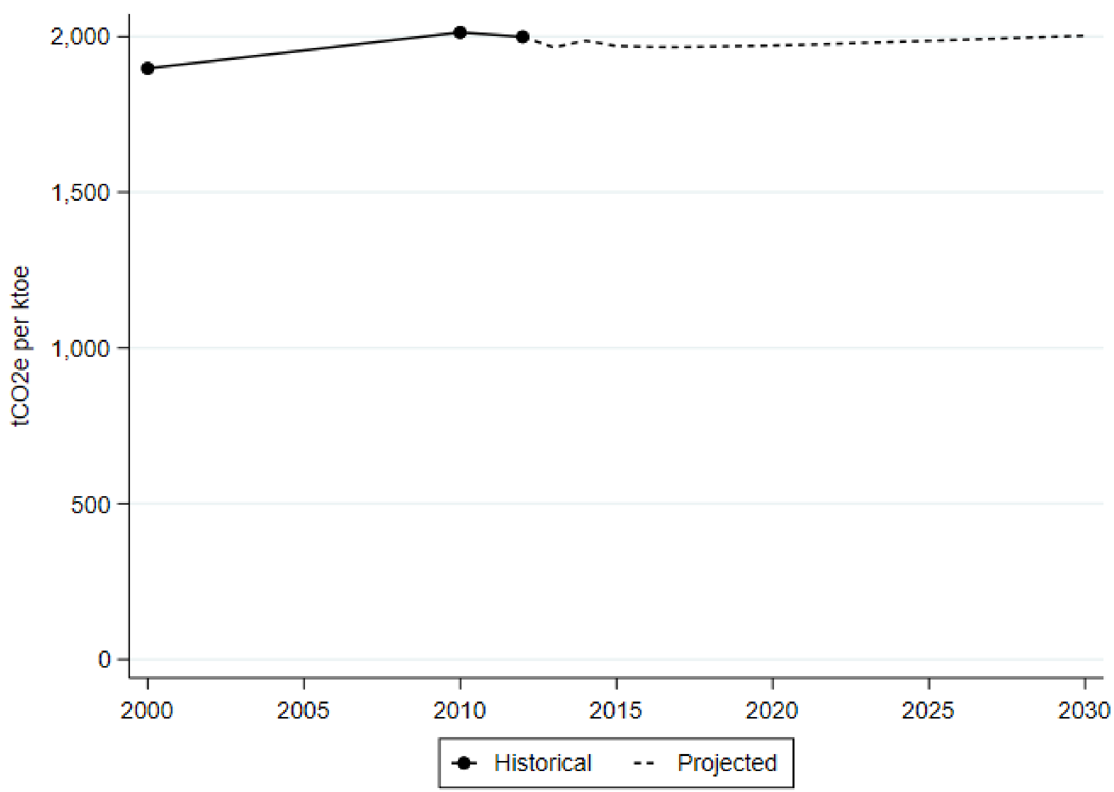

Figure C.16. Emission intensity of TPES in Singapore

Thailand

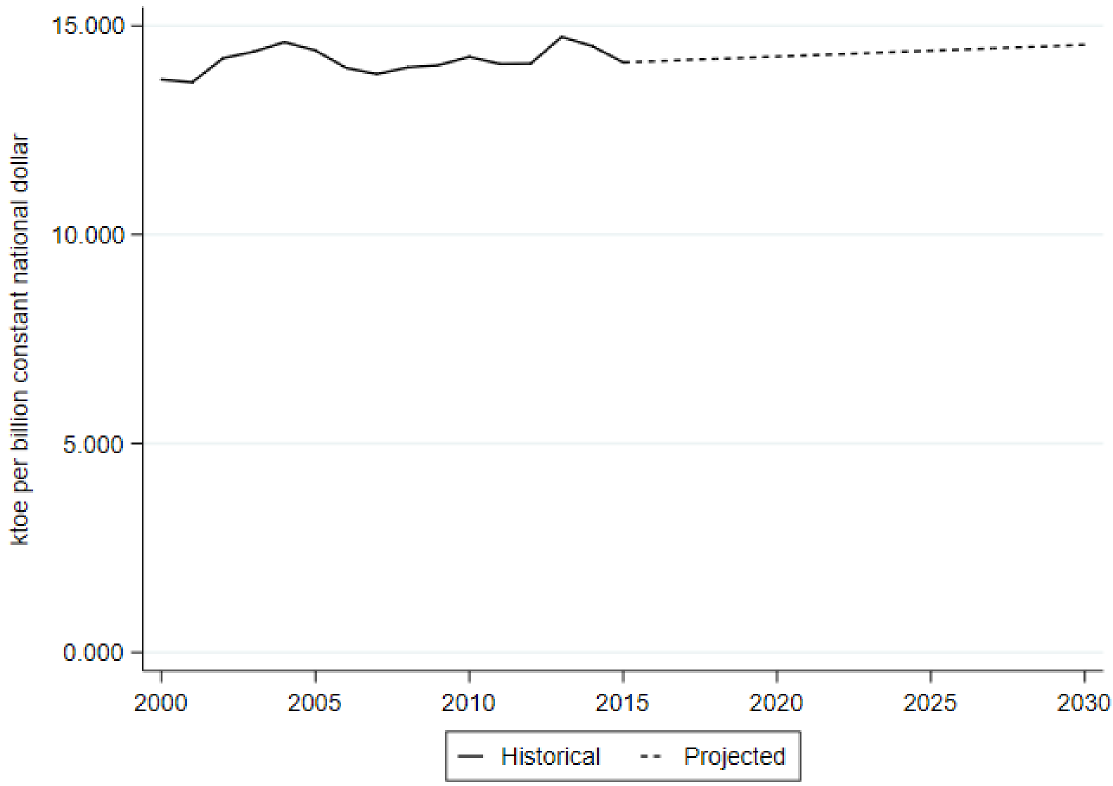

Figure C.17. Energy intensity of GDP in Thailand

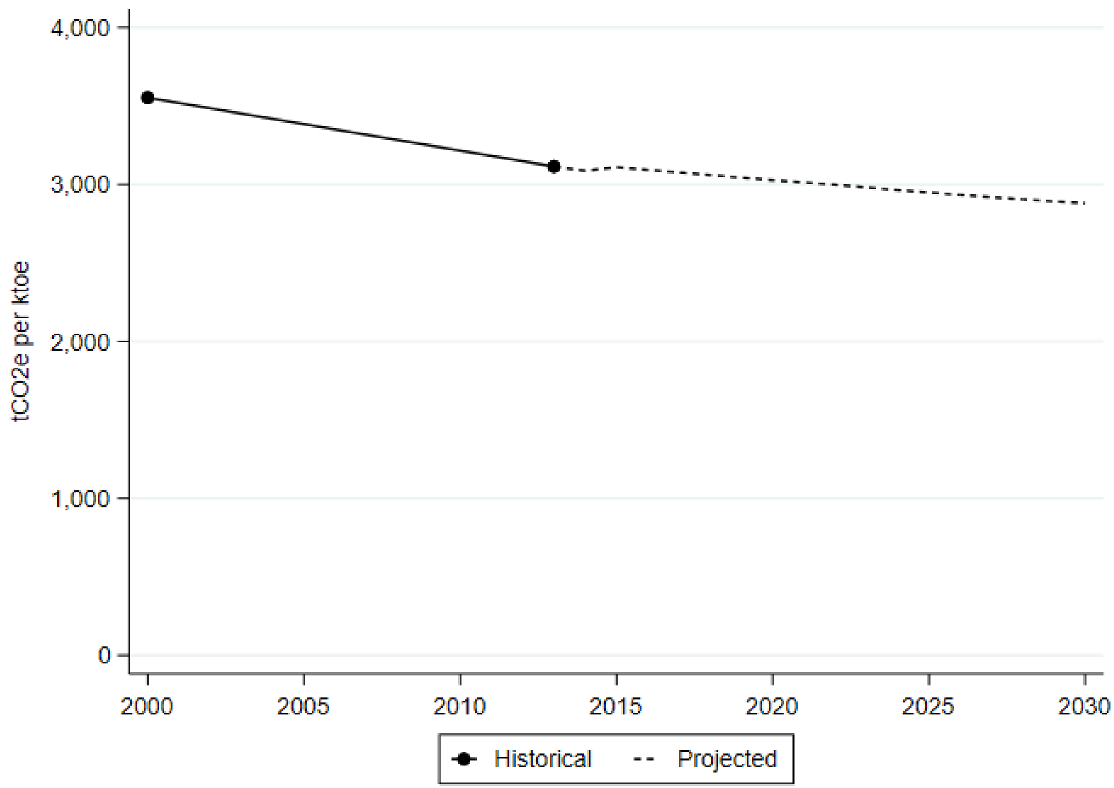

Figure C.18. Emission intensity of TPES in Thailand

Vietnam

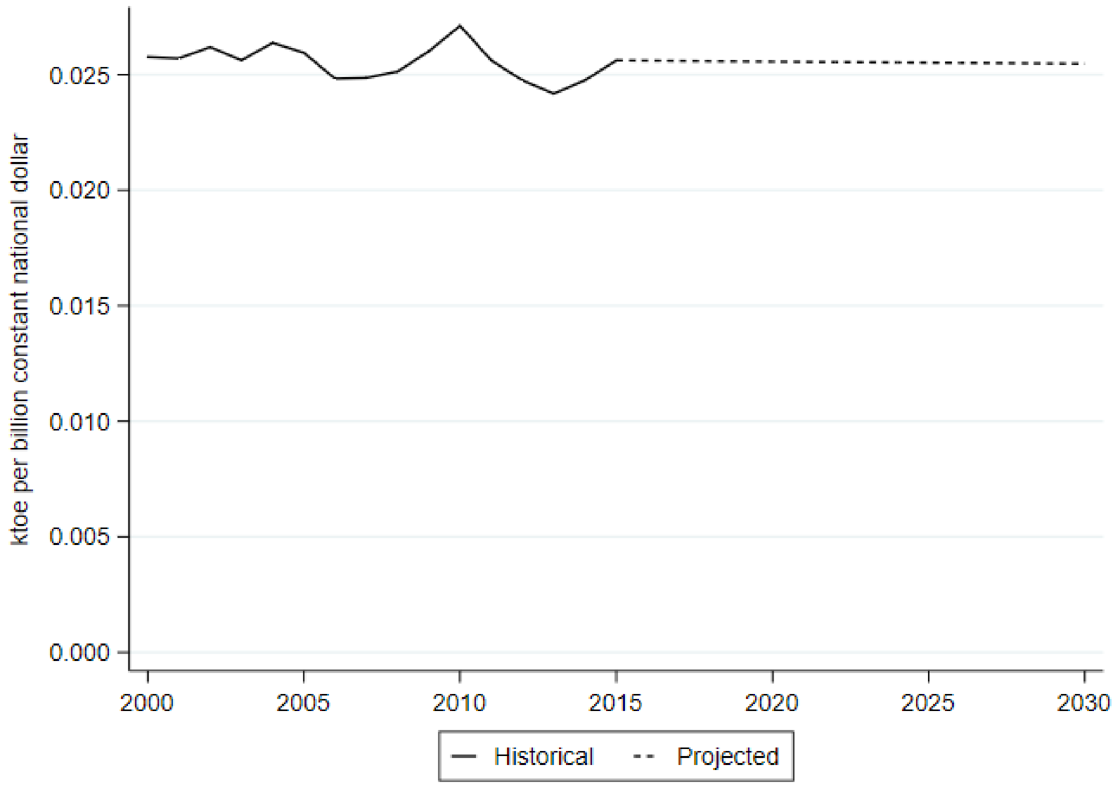

Figure C.19. Energy intensity of GDP in Vietnam

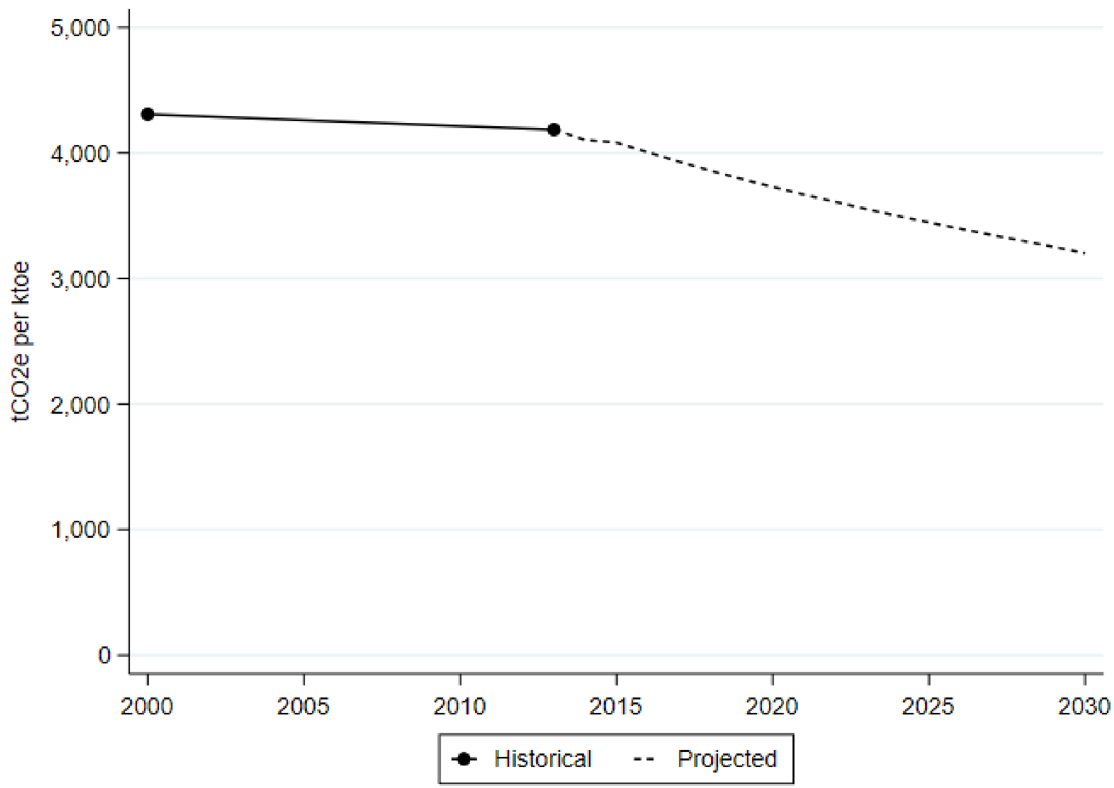

Figure C.20. Emission intensity of TPES in Vietnam

Appendix D. Non-CO_2 energy emissions

Below we provide a comparison of non-CO_2 energy emissions from IEA (2016a), IEA (2017c), and country reports to the UNFCCC. The country-reported non-CO_2 energy emissions are used in the country-level analysis. Figure D.1 illustrates non-energy CH_4 emissions while Figure D.2 depicts non-energy N_2O emissions. For comparison purposes, emissions from IEA (2016a) and IEA (2017c) are for the year 2010 while country-reported emissions are for the most proximate year with available data. Note that Lao PDR is excluded from the figures as it is not included in IEA datasets.

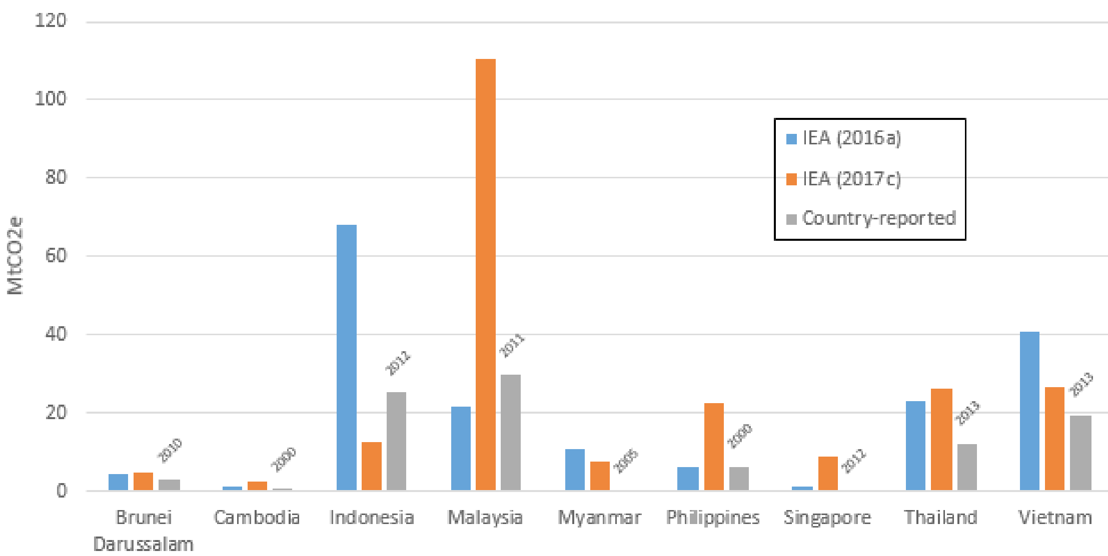

Figure D.1. Comparison of reported CH_4 from the energy sector around the year 2010

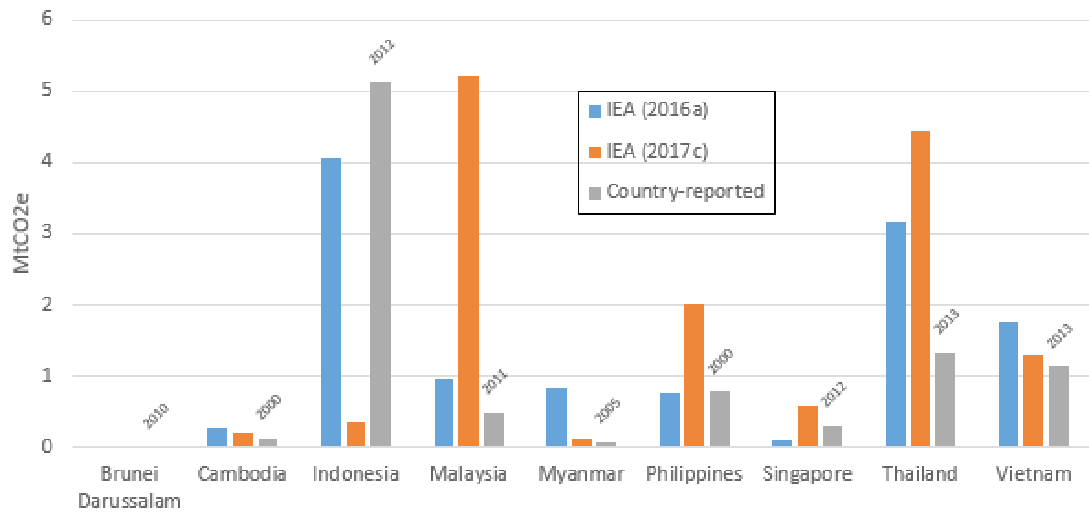

Figure D.2. Comparison of reported N_2O from the energy sector around the year 2010

Appendix E. Additional information for the economy-wide analyses

E.1. Additional information about the economy-wide model

AGE models represent interactions among three types of agents: households, firms, and the government, as illustrated in Figure E.1. Households own the primary factors of production (e.g., labor, capital and natural resources) which they rent to firms and use this income to purchase goods and services. In each sector, firms produce commodities by combining factors of production and intermediate inputs (i.e., goods produced by other sectors). The government sets policies and collects tax revenue, which it spends on providing goods and services for households and on transfer payments to households. Equilibrium is obtained through a series of markets (for both factors of production and goods and services) that determine prices so that supply equals demand.

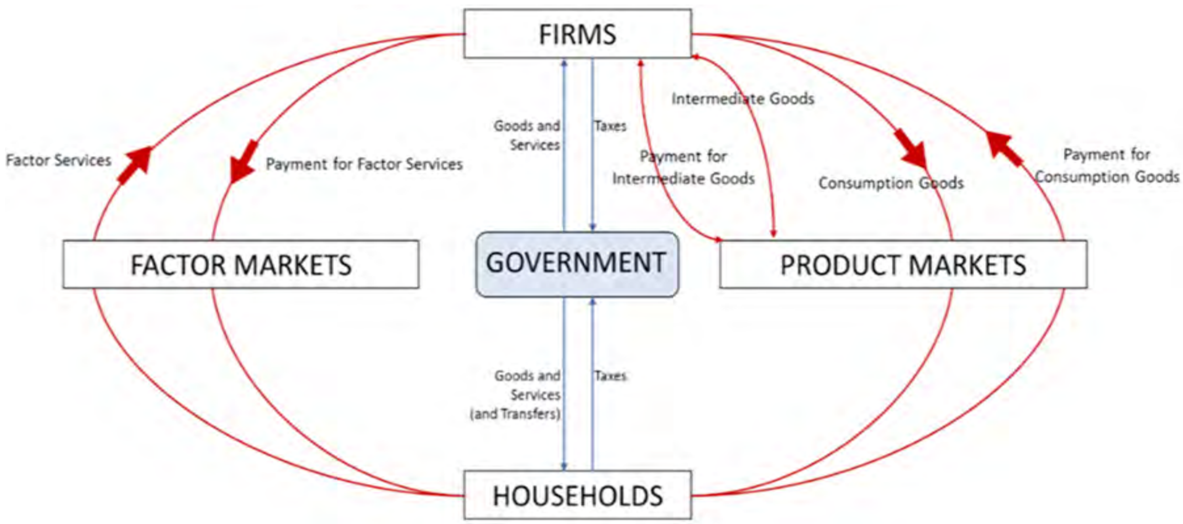

Figure E.1. The structure of an AGE Model.

An important characteristic of AGE models is the representation of inter-sectoral linkages through each firm's use of intermediate inputs. Purchases of intermediate inputs are captured in input-output tables used to calibrate AGE models. For each sector, these tables list the value of output produced and the value of each input used, which can be linked to physical quantities (e.g., tons of coal). For example, the coal power sector will use inputs of capital and labor, and output from the coal mining sector along with other intermediate inputs to produce electricity. These inter-sectoral linkages allow AGE models to evaluate how policy changes will propagate throughout an economy.

Other key features of AGE models include the representation of competition from competing technologies/sectors and substitution possibilities among inputs. For instance, an increase in the price of coal-based electricity will provide scope for the expansion of electricity generation from other sources, such as renewable electricity. At the same time, an increase in electricity prices will incent firms to use electricity more efficiently by investing in more efficient plants, at an additional cost, than they would have in the absence of the price increase.

The core structure of the AGE model used for the economy-wide analyses follows that set out by Winchester and Reilly (2018). The model is a single-country AGE model that can be readily adapted to specific economies and includes many features in the MIT Economic Projection and

Policy Analysis (EPPA) model (Chen *et al.*, 2016). As the model is static with a forward calibration to 2030, it produces estimates for each economy under alternative technology and policy options in 2030, but it does not describe the transition path between now and 2030.

We calibrate the model, separately, for Indonesia and Vietnam using the Global Trade Analysis Project (GTAP) Power Database (Peters, 2016). This database augments version 9 of the GTAP Database (Aguiar *et al.*, 2016) and includes economic data and CO_2 emissions from the combustion of fossil fuels for 140 regions and 68 sectors. We extract data for Indonesia and Vietnam and aggregate the sectors to the desired aggregates (see below) by extending tools provided by Lanz and Rutherford (2016). We also augment GTAP-Power with data on non-CO_2 emissions from Irfanoglu and van der Mensbrugghe (2015), and estimates of non-combustion CO_2 emissions from country reports to the UNFCCC (DGCC, 2015; MNRE, 2017). The base data for each model provides a snapshot of each country in 2011. We use the model to evaluate outcomes in 2030 using a forward calibration procedure outlined by Winchester and Reilly (2018).

Power generation from fossil electricity technologies is driven by fuel costs, including carbon charges if applicable. Hydroelectric power generation, which is determined by planning and regulations rather relative prices, is exogenous in all scenarios and does not respond to price changes. A base level of diesel electricity generation is also set in the model, which can be replaced with electricity from other sources depending on relative costs. For both countries, hydroelectricity power generation and the base level of diesel-powered electricity are set equal to projections for these technologies in the country-level studies.

Generation from wind and solar, and other renewables is determined by the cost of the technology and an ancillary constraint capturing factors that limit the penetration of these technologies that are not explicitly included in the model (e.g., intermittent generation and the use of inferior sites as generation from each technology expands). As IEA (2016b) projects that non-hydro renewables in Indonesia in 2030 will be almost all geothermal, we group the small amount of electricity from wind and solar in this country with other renewables. For Vietnam, the costs for generation from wind and solar in 2030 is calculated as a weighted average of projected costs for the constituent technologies. Specifically, we multiply projected costs used in the EPPA model (Chen *et al.*, 2016) ($0.056 per kWh for wind and $0.07 for solar) by estimated generation shares for each technology in Vietnam's Power Development Plan (GDE, 2017) (0.403 for wind and 0.597 for solar).

E.2. Supplementary results for the economy-wide analyses

Table E.1. Indonesia: GHG emissions in 2030, $MtCO_2e$

	BAU	UNCON-ALL	UNCON-SEL	CON-ALL	CON-SEL	CON-ALL-DIG	CON-SEL-DIG
CO_2, combustion	751.0	681.6	596.6	643.1	552.4	642.2	552.1
CO_2, non-combustion	67.3	45.2	42.2	43.9	41.0	44.1	41.2
CH_4	83.3	62.5	81.6	60.9	81.5	61.1	81.5
N_2O	243.9	173.0	242.0	168.6	241.6	169.1	241.8
F-gases	0.8	0.6	0.5	0.6	0.5	0.6	0.5
Total	1146.4	962.9	962.9	917.1	917.1	917.1	917.1

Table E.2. Indonesia: Electricity generation in 2030, TWh

	BAU	UNCON-ALL	UNCON-SEL	CON-ALL	CON-SEL	CON-ALL-DIG	CON-SEL-DIG
Coal	338.9	280.7	194.7	248.5	152.6	260.2	160.6
Gas	130.6	135.8	143.1	138.9	146.3	142.7	150.9
Oil	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Hydro	48.0	48.0	48.0	48.0	48.0	48.0	48.0
Other renewables	101.4	105.4	111.2	107.5	113.9	106.6	113.3
Total	636.9	588.0	515.1	560.9	478.8	575.5	490.8

Table E.3. Indonesia: Primary energy in 2030, Mtoe*

	BAU	UNCON-ALL	UNCON-SEL	CON-ALL	CON-SEL	CON-ALL-DIG	CON-SEL-DIG
Coal	94.99	78.40	56.05	69.25	45.19	69.21	45.33
Gas	69.53	68.71	68.05	68.21	67.15	67.97	66.96
Oil	94.16	93.06	93.75	92.36	93.50	92.33	93.40
Hydro	4.12	4.12	4.12	4.12	4.12	4.12	4.12
Other renewables	8.70	9.05	9.55	9.23	9.78	9.15	9.72
Total	271.51	253.34	231.52	243.17	219.74	242.77	219.54

* Primary energy from nuclear is based on the amount of heat generated in reactors assuming a 33% conversion efficiency. For wind, solar and hydro, the primary energy equivalent is the physical energy content of electricity generated.

Table E.4. Vietnam: GHG emissions in 2030, $MtCO_2e$

	BAU	UNCON-ALL	UNCON-SEL	CON-ALL	CON-SEL	CON-ALL-DIG	CON-SEL-DIG
CO_2, combustion	418.0	414.6	396.5	334.8	302.7	334.4	302.2
CO_2, non-combustion	81.3	61.4	54.3	49.4	42.5	49.5	42.9
CH_4	17.8	14.4	17.5	12.3	17.2	12.3	17.2
N_2O	114.3	90.4	112.6	77.1	111.1	77.3	111.2
F-gases	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	631.4	580.9	580.9	473.5	473.5	473.5	473.5

Table E.5. Vietnam: Electricity generation in 2030, TWh

	BAU	UNCON-ALL	UNCON-SEL	CON-ALL	CON-SEL	CON-ALL-DIG	CON-SEL-DIG
Coal	128.48	127.06	112.60	89.34	40.96	87.35	40.13
Gas	137.55	137.33	135.60	133.50	109.58	138.38	109.83
Oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Hydro	89.00	89.00	89.00	89.00	89.00	89.00	89.00
Wind & solar	32.13	32.18	32.58	33.42	36.38	39.29	42.84
Other renewables	12.22	12.22	12.29	12.43	12.87	12.32	12.79
Total	401.38	399.80	384.07	359.69	290.79	368.35	296.59

Table E.6. Vietnam: Primary energy in 2030, Mtoe*

	BAU	UNCON-ALL	UNCON-SEL	CON-ALL	CON-SEL	CON-ALL-DIG	CON-SEL-DIG
Coal	62.70	61.96	57.41	43.47	36.92	43.29	37.05
Gas	22.28	22.27	22.26	22.22	18.24	22.22	17.69
Oil	50.34	50.16	49.86	47.00	47.34	47.15	47.38
Hydro	7.71	7.70	7.70	7.70	7.69	7.70	7.69
Wind & solar	3.63	3.64	3.68	3.78	4.11	4.44	4.84
Other renewables	1.29	1.30	1.30	1.32	1.36	1.31	1.35
Total	148.02	147.11	142.29	125.55	115.72	126.18	116.07

* Primary energy from nuclear is based on the amount of heat generated in reactors assuming a 33% conversion efficiency. For wind, solar and hydro, the primary energy equivalent is the physical energy content of electricity generated.