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Pathways to Paris:
Latin America (LAM)

Technology and Policy Options
to Reduce GHG Emissions

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Main Takeaways

- For the Paris Agreement process, the Latin American countries pledge to reduce their emissions through 2025 or 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 ten selected Latin American countries (“LAM”) in achieving their emission mitigation targets.
- In aggregate the LAM region is making strong progress towards its Paris goals with government-led efforts to increase the use of renewables and natural gas. Under the unconditional pledges, the LAM region faces an emissions gap (i.e., the needed reduction to meet the Paris pledges) of around 60 $MtCO_2e$, which indicates that the LAM region will need additional actions to reduce emissions by 2% 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 350 $MtCO_2e$, which indicates a needed reduction of 10% by 2030.
- Individually, while some countries are projected to be close to or to even over-achieve their unconditional and conditional goals for 2030, others require additional efforts. While some LAM countries face the challenge of developing stable regulatory and legal frameworks to further encourage private investments in clean energy projects, there are many policy and technology options available to them 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., enhancing renewable energy auctions and support to natural gas infrastructure development).
- While wind and solar generation provide attractive options for lowering emissions, enhancement of natural gas infrastructure enables higher penetration of intermittent renewables by serving as backup capacity.
- Our country-specific analysis for Argentina and Colombia shows that existing plans for the expansion of non-fossil electricity generation are sufficient to meet unconditional emission reduction targets in Argentina and Colombia. Conditional emissions reduction pledges can be achieved with moderate additional policies. For example, when non-fossil electricity targets are met, the addition of an all-sectors emission trading scheme (ETS) that caps emissions at the level consistent with each nation’s conditional pledge results in carbon prices in Argentina and Colombia of, respectively, of \$2.7 and \$2.9 per tCO_2e.
- Our assessment is unique in that the gap analysis covers both larger and smaller Latin American economies and clearly documents the data and assumptions associated with our calculations. We hope the open source format of our input data and tools for analysis will enhance the capacity to analyze the Latin America countries’ pathways in 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. While the Latin American countries have shown impressive growth in renewables generation, they face the challenge of enhancing regulatory and policy frameworks to encourage private investment in clean energy projects, with the goal of further reducing their GHG emissions. To help them address this challenge, we focus on ten Latin American countries (Argentina, Brazil, Chile, Colombia, Ecuador, Mexico, Panama, Peru, Uruguay, and Venezuela—a group of countries referred to as "LAM" in this report) and use a variety of analytical tools—including country-specific, economy-wide models for two (Argentina and Colombia) countries—to understand the LAM region's aggregate 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 LAM countries in achieving their emissions mitigation targets. This assessment is enhanced by direct communication with ministerial representatives and energy experts from individual countries,[1] as well as the coordinative efforts of the Department of Sustainable Development of the Organization of American States (OAS). By maintaining an open dialogue on the data and policies incorporated in our projections, and even more, by providing all input data and tools used in our analysis in an open source format, we hope to enhance the capacity to analyze the LAM countries' pathways in meeting their energy, sustainability, and emissions goals.

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

The LAM region is an important contributor to global development. In 2010, its population accounted for about 7.2% of the global population and about 8% 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 LAM region's global share in 2010 was about 6%.[2] 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 LAM region is projected to have a steady growth in energy demand—approximately a 25% increase in total primary energy consumption from 2015 to 2030—due to its growing population and economy. Continued progress 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.

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[2] Of Latin America in its entirety, the ten countries considered in this report represent about 84% of the population, 93% of GDP PPP, and 90% of GHG emissions in 2010.

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 LAM countries' future emissions up to 2030 based on our assessment of economic growth and announced plans for energy supply and power generation (we refer to this scenario as the Policy scenario in contrast to the business-as-usual (BAU) or Baseline scenario that is based on energy trajectory without enforcing new energy plans or the Paris Agreement pledges). In 2030, the estimated Policy scenario emissions are 3,640 million tonnes of CO_2-equivalent ($MtCO_2e$). Using an MIT-developed BAU trajectory, the unconditional emissions target for LAM is calculated as 3,572 $MtCO_2e$. Consequently, the emissions gap (i.e., the volume of reductions to be achieved under a specific target) from the Policy scenario is 68 $MtCO_2e$, which indicates that, in aggregate, the LAM region will have to reduce its emissions by an additional 2% relative to the Policy scenario to meet its countries' unconditional NDC pledges. Under the conditional emissions target (3,289 $MtCO_2e$), the emissions gap is 351 $MtCO_2e$, which indicates a needed reduction of 10% relative to the Policy scenario emissions.

Achievement of NDC goals will be affected by both the type of power generation and the type of fuel for transportation and industry 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. Nevertheless, while wind and solar generation provide the most attractive options for lowering emissions, further development of natural gas infrastructure in the LAM region would enable higher penetration of intermittent renewables by serving as backup capacity. Some LAM countries are already leading the way in this area. Brazil, for example, maintains three floating storage regasification units (FSRUs), with plans for a fourth unit, to support the country's substantial LNG imports, which provided crucial backup generation when droughts impacted hydropower output in 2012 to 2016 (Goldwyn and Clabough, 2018).

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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 these 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, constitutional or statutory property rights, or state contracts and transparent dispute settlement procedures guaranteeing the rights of investors, are a key factor determining the ability of countries to attract clean energy investment.

Currently, electricity market designs are again facing substantial pressure to transform. Emergence of disruptive technologies, such as distributed energy resources, energy storage, and digitalization, coupled with ever more stringent environmental policy requirements, are fundamentally changing the landscape in which energy markets operate. Design of electricity markets, for instance, needs to facilitate the integration of all 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, for instance via 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 and to better integrate intermittent and distributed resources (Denmark provides an example of a country where good connections with neighboring countries allows for a substantial uptake in wind power).

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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. Some LAM countries are already well into the subsidy removal process. Chile, for example, has removed almost all of its energy sector subsides, with the exception of a measure supporting low income households in the event of an electricity price spike. The country otherwise avoids government intervention in electricity pricing and has 100% private participation in generation, transmission, and distribution.

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For the LAM 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. These instruments are particularly suitable for countries with substantial experience with market-based mechanisms and competitive electricity markets. Already, a handful of LAM countries (Argentina, Chile, Colombia, and Mexico) have implemented targeted carbon prices in some sectors, and interest in this highly cost-effective and scalable policy option is high with several LAM countries considering adoption of a carbon tax or an ETS as part of their national strategies. International experience with such markets is extensive (for an overview of experience, see Section 7.3 of the report).

For countries where a carbon tax or ETS is not currently feasible, we recommend an initial focus on technology-specific policies such as renewable energy auctions and renewable portfolio standards. 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. In Uruguay, for example, a $5.68 billion renewables investment program and reverse auction increased wind and solar output nearly twenty-fold from 2011 to 2015 and pushed the country to around 95% of generation from renewables by 2015. 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.

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In the medium-term, enhancement of natural gas infrastructure could enable higher penetration of intermittent renewables by serving as backup capacity. 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 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., China, Egypt, and in LAM, Mexico) 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.

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critical to secure investment decisions and implement and execute projects. This 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.

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.

Further progress towards emission mitigation goals can be achieved by a reduction and eventual elimination of fossil fuel subsidies. Although fossil fuel prices in most LAM countries fluctuate based on prices in international markets, they remain regulated and are not fully liberalized. As electricity demand is growing in LAM countries, a reform in electricity subsidies 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 energy subsidies in Chile, reducing electricity subsidies in Argentina, and reforming discretionary electricity pricing mechanisms in Mexico), combined with creation of targeted support to low-income consumers.

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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 in 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. However, 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, battery energy storage, 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. Most LAM nations have already adopted new technologies for emissions reduction. As countries update their NDCs, however, there is an opportunity to create frameworks that encourage further private investment in these technologies to further improve the efficiency of the power sector and reduce emissions.

The LAM countries are still at relatively low levels of penetration of intermittent renewables, and therefore, their integration into the power system is currently relatively simple. LAM 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 intermittent renewables (e.g., Germany, Denmark, Belgium, and Portugal) provides valuable guidance for understanding challenges and opportunities of intermittent generation sources.

As LAM countries continue to develop their wind and solar generation fleets, natural gas can be a resource to manage the intermittency of these zero carbon options. Many LAM nations are introducing 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—e.g., as in relatively heavily coal-powered Chile, where the government has placed a moratorium on new coal plants without CCS—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.

We emphasize that other technologies may become more attractive in the future. Possible options include advanced long-term 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. Nevertheless, mitigation strategies most likely need to employ a set of different options in different sectors of the economy rather than achieve all emission reductions exclusively in the power generation sector.

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Deep Dive: Argentina and Colombia

Targets for renewable electricity (including planned increases in electricity from nuclear and hydro) combined with business as usual efficiency improvements are sufficient to meet unconditional pledges in Argentina and Colombia. In both countries, more-stringent conditional emission targets can be achieved with moderate additional policies. For example, an economy-wide ETS that caps emissions at the conditional level resulted in carbon prices in Argentina and Colombia of, respectively, \$6.8 and \$2.9 per tCO_2e.

The key insight here is that the sectoral coverage of climate policy should be a broad as possible.

However, when the ETS only covered electricity and energy-intensive sectors, the carbon prices were much higher (\$419.6 and \$602.5 in, respectively, Argentina and Colombia) and the GDP costs were greater. The key insight here 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.

The simulations also showed that adding an RPS to an all-sectors ETS increased the cost of meeting emission targets (even though it decreased the carbon price). This is because the RPS reduced emissions in only the electricity sector and it did so in a specified way (increasing the share of electricity from non-fossil sources). Notably an RPS does not penalize coal electricity for its higher CO_2 intensity relative to gas power, so it does not incent a shift from coal to gas generation. In contrast, an economy-wide ETS reduces emissions wherever and however emission reductions are cheapest. These findings illustrate the well-established concept that regulations (e.g., a RPS) are more costly than market-based measures (e.g., a carbon price evolving under an ETS).

Simulations evaluating the impact of digitalization indicated that greater adoption of digital technologies can reduce the cost of meeting emission targets while at the same time increasing electricity generation.

Policy Recommendations for Argentina

Argentina has made considerable progress with its energy and climate policies in recent years, deregulating gas and electricity prices, strengthening its policies to accelerate growth of renewable energy, and introducing a carbon tax on fossil fuels. Robust implementation of the RenovAr auctioning platform (including the penalties for delays and default on contracted terms), continued expansion of electricity transmission infrastructure and grid interconnections, responsible development of its abundant shale gas reserves, and further expansion of the carbon price are all recommended for continued decarbonization in line with Argentina's NDC pledge.

In recent years, Argentina has deregulated gas and electricity prices, strengthened its policies to accelerate growth of renewable energy, and introduced a carbon tax on fossil fuels.

Argentina was the first country to revise and strengthen its NDC following the election of President Mauricio Macri. Unveiled at COP22 in 2016, the revised NDC is significantly more ambitious than the original pledge, partially due to a changed methodology for quantifying historical emissions data. This step signalled a reversal of how prior governments had approached climate change, affording it limited weight relative to the priority of economic recovery and social development after the crisis of 2001. For much of the decade, scarcity of capital, price-distorting subsidies, and political risk combined to make Argentina a relatively unappealing destination for clean energy investment. Under the new government, legal and administrative reforms to strengthen institutional capacity, rebuild investor trust, and liberalize energy markets offer a unique opportunity to advance Argentina's climate policy performance.

Institutionally, the new government has upgraded the executive agency responsible for environmental protection to the level of ministry, designating it the Ministry of Environment and Sustainable Development (Ministerio de Ambiente y Desarrollo Sustentable, or MAyDS). Within the ministry, climate change falls into the purview of the Office of the Undersecretary of Climate Change and Sustainable Development (Subsecretaría de Cambio Climático y Desarrollo Sustentable) and the newly established National Directorate of Climate Change (Dirección Nacional de Cambio Climático, or DNCC). Also newly created is an National Cabinet on Climate Change (Gabinete Nacional de Cambio Climático, or GNCC), a working group composed of members from 17 different ministries that is coordinated by MAyDS and has the task of elaborating the strategies and instruments to implement national climate objectives.

As projected by our modeling framework, future emissions growth in Argentina will largely center in the energy sector.

As projected by our modeling framework, future emissions growth in Argentina will largely center in the energy sector. Rapid growth in electricity demand and related power sector emissions, coupled with a relatively ambitious NDC, offer a significant opportunity for renewable energy deployment. Recent developments in energy legislation suggest that Argentina is looking to harness this opportunity. Under Law N° 27.191, passed on 15 October 2015, it has increased earlier targets for the share of renewable energy (other than large hydro) in electricity consumption to 8% by the end of 2018, 12% by 2019, 16% by 2021, 18% by 2023 and 20% by 2025.

An early system of modest feed-in tariffs adopted in 2006 under Law N° 26.190 proved relatively ineffective in driving renewable energy investment, and was narrowed to facilities with generating capacity below 30 MW under Law N° 27.191. Instead, Argentina has joined many of its neighboring countries by relying on reverse auctions for long-term Power Purchase Agreements (PPAs) to promote the development of renewable energy. As early as 2010, it launched the Renewable Energy Generation Program (Programa de Generación de Energía Eléctrica a partir de Fuentes Renovables, or GENREN) tender program, requiring the state utility (Energía Argentina Sociedad Anónima, or ENARSA) to contract at least 1 GW of renewable energy capacity and sell it to the grid at fixed rates for a period of 15 years. Although this early scheme yielded 1.4 GW in offers and 895 MW in signed contracts, only 128 MW ended up actually being commissioned. Lack of financing due to high perceived sovereign and offtaker risk were cited as the primary reason for this weak outcome.

In execution of Law N° 27.191 and its implementing Decree N° 531/2016, the Ministry of Energy and Mining (Ministerio de Energía y Minería) has elaborated a new renewable energy auctioning program (Plan de Energías Renovables Argentina 2016-2025, or RenovAr) featuring a reverse auction bidding process to contract renewable electricity. It addresses the shortcomings of the GENREN program by lowering risk and ensuring better financial conditions for bidders. This time, the liquidity of the offtaker of contracted electricity, the Wholesale Electricity Administrator Company (Compañía Administradora del Mercado Mayorista Eléctrico, or CAMMESA), is backed by a newly created Fund for the Development of Renewable Energies (Fondo para el Desarrollo de las Energías Renovables, or FODER). Through this fund, the government serves as trustor and residual beneficiary, the Bank of Investment and Foreign Trade (Banco de Inversion y Comercio Exterior, or BICE) as trustee, and owners of investment projects are the beneficiaries. Itself backed by a World Bank guarantee, FODER protects bidders from offtaker, PPA termination, currency conversion, and certain political risks.

A value-added tax (VAT) rebate, accelerated depreciation rules, and additional income tax and import duty benefits (including a local content rule) further improve the financial viability of renewable energy projects, as do improved transparency requirements about nodal capacities and potential transmission constraints. PPAs awarded under RenovAr have a duration of 20 years and are denominated in US$, but paid in Argentinian Pesos using a conversion mechanism and adjusted by an incentive factor to promote fast project completion. Under Decree N° 531/2016, large consumers, defined as those with average consumption exceeding 300 kW, can opt out of the tendered PPAs and obtain their supply directly from a distributor or from the wholesale market at a price ceiling of $113 per MWh or through self-generation of cogeneration.

RenovAr has so far resulted in three electric power auctions: Round 1, Round 1.5 and Round 2. Under the first round, it solicited bids for 1,000 MW of renewable energy to the grid, broken down by technology: 600 MW of wind, 300 MW of solar, 65 MW of biomass, 20 MW from small dams, and 15 MW from biogas. It yielded submissions from over 75 companies for 123 projects amounting to 6,346.3 MW in proposals, making the tender six times oversubscribed. Overall, the three RenovAr bidding rounds have resulted in awards to 147 projects for a combined capacity of 4,466.5 MW, evidencing the successful uptake of this instrument as a mechanism to promote renewable energy investment: in 2017, Argentina attracted more investment in one calendar year than in the prior six years combined. With average prices in each auction falling from $59.70 per MWh in Round 1 (July 2016) to $40.40 per MWh in Round 2 (November 2017), however, there have been concerns that developers may be undervaluing assets and bidding below actual project cost, which may compromise their ability to secure financing and make a final investment decision. Initial delays with the execution of projects awarded so far suggest that these concerns are not unfounded, meriting close scrutiny going forward.

Aside from RenovAr, Argentina has introduced several additional programs to promote renewable energy in power generation and transportation. Renewable electrification of remote rural areas is promoted under the Project on Renewable Energy in Rural Markets (Proyecto de

Energías Renovables en Mercados Rurales, or PERMER), which has recently entered a second phase. Meanwhile, Law N° 26.093 of 12 May 2006 and its implementing regulations introduced mandatory fuel blending quota for bioethanol and biodiesel in transportation fuels, and currently mandate a 10% share of biodiesel in diesel fuels and 12% of bioetanol in gasoline.

More generally, Argentina has made important progress in reforming its market for electricity and gas. Already one of the most deregulated electricity markets in Latin America, with around 75% of generation capacity in private ownership, Argentina has also recently liberalized electricity and gas pricing. Following the economic recession and fiscal crisis of 2001, the government had responded to political pressure about the cost of energy by fixing electricity and gas prices, which, over time, prompted a considerable decline in infrastructure investment and threatened the security of supply. Despite abundant domestic resources—both conventional and renewable—Argentina therefore faces a current power deficit. Over considerable resistance, the new government has repealed price subsidies for electricity and gas, bringing these closer to real cost.

With around 75% of generation capacity in private ownership, Argentina already has one of the most deregulated electricity markets in Latin America, and has also recently liberalized electricity and gas pricing.

On the latter front, Argentina is set to join the small number of Latin American countries which have introduced a carbon price when it implements a carbon tax (impuesto al dioxido de carbono) from 1 January 2019. Adopted on 28 December 2017 as part of a comprehensive tax reform, the carbon tax will be imposed as a percentage of the full tax rate of US$ 10/tCO_2e. For most liquid fuels, the tax will be levied at the full rate, whereas for mineral coal, petroleum, and fuel oil, the tax rate will at a tenth of the full tax rate, increasing annually by 10 percent to reach 100 percent in 2028. Producers, distributors and importers of these fuels are liable for payment of the tax, although certain sectors and uses are partially exempt, such as international aviation and shipping, fuel exports, the share of biofuels in mineral oil, and raw materials used in (petro)chemical processes. Altogether, the tax is expected to impose a carbon price on approximately 20% of Argentina's emissions.

Going forward, Argentina faces numerous policy challenges as it pursues implementation of its climate pledges. Given initial delays under the landmark RenovAr tendering program, the country has to demonstrate the capabilities of this new incentive framework to ensure reliable deployment of renewable energy sources in electricity generation, with robust enforcement of the penalties for delays or default on the part of project developers. For its part, the government should continue pursuing its tendering process for new transmission infrastructure. In a country where a large share of renewable resources are located in the windswept Patagonia region that is covered by a separate grid (Sistema de Interconexión Patagónico, or SIP), adequate interconnection with the country's main grid (Sistema Argentino de Interconexión, or SADI) will be key to mitigate any curtailment risk for both renewable and thermal generators.

Abundant shale gas reserves in the Vaca Muerta Formation offer an opportunity to simultaneously address energy security concerns and provide a dispatchable, lower-carbon bridge fuel to balance the growing share of variable renewable sources in electricity generation until battery storage is economically more viable. Attracting foreign investment through robust legal guarantees, fiscal incentives, and adequate infrastructure is vital to accelerate the pace of natural gas exploration and extraction. Care has to be taken, however, to develop these resources responsibly, addressing environmental impacts such as methane leakage, and considering the longer term evolution of the national and global energy system when locking in investment and associated emissions over significant periods of time.

An important step in this regard is the recent introduction of a carbon tax, which can help correct the central market failure underlying climate change. By signaling a more accurate cost of emissions from the production and consumption of fossil fuels, the carbon price can help investors align their investment strategies with decarbonization pathways. Over time, therefore, Argentina should consider expanding the scope of the carbon price beyond the current sectors and activities to cover the economy at large, and increasing the tax rate to a level more consistent with the estimated social cost of carbon. Together with removal of distorting energy subsidies and continued liberalization of the electricity market, these measures can ensure that Argentina meets its growing energy needs in a secure, affordable, and, above all, environmentally sustainable manner.

Policy Recommendations for Colombia

Colombia has made significant progress in the development of a robust climate and renewable energy policy framework. Recent advances include the adoption of a national framework law on climate change, the introduction of a carbon tax, and targeted pursuit of greater diversification in the electricity mix through auctioning. Still, abundant domestic reserves of oil and coal pose a challenge to the meaningful reduction of greenhouse gas emissions in the energy sector, including in transportation. Intensified land-use in post-conflict areas has also contributed to a concerning rise in emissions from tropical deforestation. To tackle these challenges, Colombia should expand the use of economic instruments such as carbon pricing and ensure a level playing field for all energy sources, continue investing in energy efficiency and clean alternatives for electricity generation and transportation, and carefully manage its ongoing land reform process.

Colombia is among the most vulnerable countries to climate change in Latin America, affording it a powerful incentive to contribute to global efforts on climate change mitigation. It has played a constructive role in international climate negotiations, and is one of the regional pioneers in comprehensive and progressive climate policies, such as a national framework law on climate change and a carbon tax. At the same time, sustaining a fragile peace in the formerly war-torn country and ensuring continued economic growth remain central priorities of the national government. Colombia therefore faces pressure to expand the development of its ample oil and coal reserves, solidifying the role of fossil fuels in the domestic energy mix. Together with a regional expansion of agriculture into previously inaccessible areas, resource extraction has contributed to a recent spike in tropical deforestation rates, posing a serious challenge to meaningful reduction of domestic emissions. This broader context explains some of the particularities of Colombia's current approach to climate and energy policy.

Recently, Colombia has adopted a national framework law on climate change, introduced a carbon tax, and targeted pursuit of greater diversification in the electricity mix through auctioning.

Colombia is among the most vulnerable countries to climate change in Latin America, affording it a powerful incentive to contribute to global efforts on climate change mitigation.

Institutionally, the National Economic and Social Policy Council

(Consejo de Política Económica y Social, CONPES), Colombia's highest authority for national planning, is the body charged with translating climate change components into policy documents. On 14 July 2011, it adopted CONPES 3700 on the Institutional Strategy for the Articulation of Policies and Actions in Climate Change, recommending the establishment of a National System of Climate Change (Sistema Nacional de Cambio Climático, SISCLIMA) as the institutional framework for the coordination and promotion of climate policy. Presidential Decree 298 of 24 February 2016 formally established SISCLIMA, which consists of several government entities—including the Ministries of Environment and Sustainable Development, Interior, Finance, Agriculture and Rural Development, Mines and Energy, Transport, Foreign Relations, and National Planning—as well as state, private and civil society entities. Its mandate includes "coordinating, articulating, formulating, monitoring, and evaluating policies, rules, strategies, plans, programs, projects, actions and measures on matters related to climate change adaptation and the mitigation of greenhouse gases" (Government of Colombia, 2016a: Article 1). SISCLIMA is managed by the Intersectoral Comission on Climate Change (Comisión Intersectorial de Cambio Climático, CICC), which is, in turn, operated by the National Planning Department (Departamento Nacional de Planeación, DNP) and the Ministry of Environment and Sustainable Development (Ministerio de Ambiente y Desarrollo Sostenible, MADS), as well as nine Regional Climate Change Nodes (Nodos Regionales de Cambio Climático, NRCC).

In its work, SISCLIMA is guided by several national strategies and planning documents, including the National Climate Change Adaptation Plan (Plan Nacional de Adaptación al Cambio Climático, PNACC), the National REDD+ Strategy (Estrategia Nacional para la Reducción de las Emisiones debidas a la Deforestación y la Degradación Forestal de Colombia, ENREDD+), the Strategy for Fiscal Protection Against Natural Disaster (Estrategia de Protección Financiera ante Desastres), and the Colombian Low Carbon Development Strategy (Estrategia Colombiana de Desarrollo Bajo en Carbono, ECDBC), and the National Climate Finance Strategy (Estrategia Nacional de Financiamiento Climático). Within a year after its formal establishment, SISCLIMA published a National Policy on Climate Change (Política Nacional de Cambio Climático, PNCC), which builds upon all the foregoing strategy and planning documents, and provides guidelines for climate planning and management at the sectoral, local, departmental, regional, and national levels.

In 2015, the Colombian government launched a project to elaborate a national climate change law, resulting in a draft law being submitted to the national legislature (Congreso de la República de Colombia) on 9 August 2017. The law passed through relevant committees in the Senate (Senado) and the House of Representatives (Cámara de Representantes) in June 2018, and was adopted in a plenary vote followed by signature of the President in late July 2018, allowing its entry into force just before the national elections in early August. Adopted as Law 1931 of 27 July 2018, the new law defines concepts and principles governing national climate change policy, formally enshrines SISCLIMA in federal law and establishes a National Climate Change Council (Consejo Nacional de Cambio Climático) as a permanent organ of the CICC, delineates the national system on climate change information and establishes a national greenhouse gas registry (Registro Nacional de Reducción de las Emisiones de Gases de Efecto Invernadero, RENARE), and sets out economic instruments to address climate change, including a National Program of Tradable Greenhouse Gas Emission Quotas (Programa Nacional de Cupos Transables de Emisión de Gases de Efecto Invernadero, PNCTE).

Colombia already has been gaining experience with economic instruments to address climate change. Law 1819 of 2016 introduced a carbon tax on the sales and imports of fossil fuels, including all liquid petroleum derivatives and natural gas for industrial uses, but exempting coal and natural gas used for electricity generation as well as exported fuels. From 1 January 2017, these fuels have been taxed based on their carbon content at a tax rate of approximately US$5/$tCO_2$, increasing annually by the rate of inflation plus one percentage point until the price reaches approximately US$10/$tCO_2e$. Decree 926 of 2017 added an option for regulated entities to reduce their tax liability by becoming certified as "carbon neutral" through use of eligible offset credits. In the first semester of 2017, approximately 2 $MtCO_2$ of offsets were surrendered to lower the tax liability of covered entities. Revenue collection and administration is conferred on the National Directorate of Taxes of Colombia (Dirección de Impuestos y Aduanas Nacionales, DIAN) is in charge of the administration and revenue collection, whereas the Ministry of the Environment and Sustainable Development oversees the emissions reporting as well as the accredited verification entities. Revenue from the tax—estimated at approximately US$ 220 million per year—flows into a fund for environmental sustainability and sustainable rural development in former conflict zones (Fondo para una Colombia Sostenible).

In the area of energy, Colombia—which already draws around two thirds of its electricity generation from hydroelectric sources—is favored by considerable renewable energy potential, including biomass, geothermal and solar energy, as well as some of the most favorable conditions for wind energy on the continent. An abundance of affordable domestic fossil fuel resources, including the largest known deposits of coal in South America, has however dampened uptake of alternative energy so far. Promoting the development of renewable energy is therefore an acknowledged priority for the achievement of Colombia's mitigation objectives. Another factor has added urgency to diversification of the country's energy supply: in recent years, increased climate variability, manifesting itself in alternating periods of heavy rain and extended droughts, has undermined the reliability of hydroelectric power, contributing to an energy crisis in 2016. To date, this has prompted growing reliance on fossil-fueled thermal energy.

> *Colombia—which already draws around two thirds of its electricity generation from hydroelectric sources—is favored by considerable renewable energy potential, including biomass, geothermal and solar energy, as well as some of the most favorable conditions for wind energy on the continent.*

Institutionally, energy falls under the jurisdiction of the Ministry of Mines and Energy (Ministerio de Minas y Energía, MME), which is responsible for policymaking and supervision of energy markets. An Energy and Mining Planning Unit (Unidad de Planeación Minero Energética, UPME) assists the ministry with advice and support in planning and implementation, and the Energy and Gas Regulation Commission (Comisión de Regulación de Energía y Gas, CREG) regulates trading, transmission, distribution, generation, and interconnection. Colombia's electricity market is governed by Laws 142 and 143 of 1994, which divide the power market into four activities: generation, transmission, distribution, and retail. Colombia has been a pioneer in electricity market deregulation, implementing a wholesale power market in 1995 and—uniquely for Latin America—extending competition to the retail level. Power can either be traded through the spot market or through bilateral contracts.

On renewable energy, Colombia adopted a Program for the Rational and Efficient Use of Energy and Other Forms of Non-Conventional Energy (Programa de Uso Racional y Eficiente de la Energía y demás Formas de Energía No Convencionales, PROURE) in 2010, committing to indicative targets and timetables for renewable energy deployment. Specifially, it aims to achieve a share of renewable (other than large hydroelectric) generation of 6.5% in on-grid and 30% in off-grid generation by 2020. In addition, Colombia enforces blending mandates of 10% biodiesel in conventional diesel and 10% ethanol in conventional gasoline. On a more programmatic level, Law 1665 in 2013 endorsed the statute of the International Renewable Energy Agency (IRENA) and its broader objectives.

One year later, in 2014, Colombia adopted Law 1715 to promote the integration of renewable energy, including forestry and agricultural biomass, solid waste, reforestation activities, solar, wave, wind, small hydropower, and geothermal energy, into the electric grid, and to promote self-consumption of electricity generated in off-grid areas. It mandates the harmonization of environmental requirements, the development of environmental impact assessment procedures for renewable energy projects, and the establishment of a rapid assessment cycle for renewable energy projects. Under this law and subsequent decrees, small-scale generators under 1 MW of generating capacity can benefit from simplified procedures and net metering.

Additionally, investors in renewable energy equipment can claim several tax benefits, including: an income tax deduction of 50% of investment value for up to 50% of taxable income for up to 5 years; an exemption from the Value-Added Tax (VAT), which currently stands at 19%, for renewable energy equipment and services; an import duty exemption for renewable energy equipment not produced locally; and accelerated depreciation of up to 20% per year for renewable energy investments. Law 1715 also contains provisions to further develop, execute, and finance PROURE, and to establish best practices for public sector energy efficiency, targets for energy-efficient government buildings, and incentives for the development and implementation of demand-response infrastructure.

Several public funds provide financial support for renewable energy projects, including a Fund for Non-Conventional Energies and Efficient Energy Management (Fondo de Energías No Convencionales y Gestión Eficiente de la Energía, FENOGE) created by Law 1715, a Rural Electrification Fund (Fondo de Apoyo Financiero para la Energización de las Zonas Rurales Interconectadas, FAER) approved in 2003 and a Fund for the Electrification of Non-interconnected Zones (Financiero para la Energización de las Zonas no Interconectadas, FAZNI) established in 2000. Each of these funds is financed by allocation of a small surcharge on wholesale energy prices.

Legal mandates and financial incentives are also in place to promote energy efficiency. Law 697 on the Rational and Efficient Use of Energy and the Use of Non-Conventional Energy Sources of, in particular, along with several subsequent decrees, set out general principles on energy efficiency, sectoral energy savings targets, and technology mandates for specific issues such as efficient lighting. In 2016, UPME published a roadmap for directing smart grid investment through 2030, focusing on four areas: smart metering roll-out, distribution automation, distributed energy integration and electric vehicle adoption. It anticipates that, by 2030, the planned investment will reduce outages from an average of 29.5 hours per year per Colombian household to 5.4 hours.

Overall, Colombia has elaborated a comprehensive framework of laws and regulations for climate change mitigation and the promotion of renewable energy. Institutionally, SISCLIMA ensures a degree of coordination across government agencies, and progress is also being made in streamlining administrative actions at the national and regional level. With competition at the wholesale and retail level, the Colombian electricity market is among the most deregulated in Latin America. Together, this provides a solid basis for further advances in domestic climate policy and expanded use of Colombia's abundant low-carbon energy resources.

There is room for further improvement, however. While Colombia's pioneering role in introducing a price on carbon marks and important step to internalize the environmental cost of fossil fuel combustion in consumer behavior, it exempts coal and gas used in electricity generation. The latter stand to become a rapidly growing source of greenhouse gas emissions as the country grapples with climate-induced volatility in hydroelectric generation, and is forced to rely on dispatchable thermal generation to balance unanticipated shortfalls. Tax benefits for renewable energy sources are an important step in achieving a more diverse electricity mix, but have not yet had a significant impact on renewable energy penetration rates given abundant and low-cost fossil fuel supplies. As renewable energy technologies decline further in price, Colombia should consider reducing and eventually phasing out fiscal subsidies for all energy sources while extending carbon pricing—potentially through an emissions trading system, as allowed under the recently adopted Law 1931—to coal and natural gas, and ensuring price levels that better reflect the social cost of carbon emissions. This can achieve a level playing field across energy sources and better complement the aim of a competitive, deregulated electricity market.

As renewable energy technologies decline further in price, Colombia should phase out fiscal subsidies for all energy sources while extending carbon pricing—potentially through an emissions trading system—to coal and natural gas, ensuring price levels that better reflect the social cost of carbon emissions.

In the near term, targeted auctions for renewable energy can play a useful role in progressing the diversification of the Colombian electricity mix, and preventing further lock-in of long-lived carbon-emitting generation assets. A government decree issued in March 2018 to "strengthen the resilience of the electricity generation matrix to events of variability and climate change through risk diversification" and a resolution issued in August 2018 by MME establish guidelines for long-term contracting of electricity generation through auctions, including eligibility conditions and a system of guarantees. A first auction for 3,443,000 MWh of generation—or roughly 4.35% of projected electricity demand in 2022—has been scheduled for January 2019. Although all electricity sources are eligible, low- and zero-carbon technologies are heavily favored in the calculation of the award criteria. Aside from renewable energy sources, this can also improve the prospects for development of the country's significant, but largely untapped, natural gas reserves located in the Northern Coast and Barranca regions, and in the La Guajira department in northern Colombia.

Colombia's relatively modest carbon tax on fuel will likely prove insufficient to meaningfully curb emissions in the transportation sector.

The relatively modest carbon tax on fuel will likely prove insufficient to meaningfully curb emissions in the transportation sector, calling for consideration of additional measures—including targeted investment in public transportation and electric vehicle infrastructure—or an accelerated increase of carbon tax rates. Beyond the energy sector, improved land use planning and the shape of future land reform will be critical to manage a concerning trend of increased deforestation. Similarly, mining and extraction activities have the potential to significantly increase Colombian greenhouse gas emissions, requiring careful balancing of economic and environmental interests. Finally, to better understand the country's emissions profile, the elaboration of a national greenhouse gas emissions registry as envisioned in Law 1931 is an important step that merits allocation of required administrative and financial resources.

International Experiences

In aggregate the LAM region is making strong progress in GHG emissions mitigation and many successful policies can serve as valuable examples for other parts of the world. At the same time, countries in the LAM region 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.

In aggregate the LAM region is making strong progress in GHG emissions mitigation and many successful policies can serve as valuable examples for other parts of the world.

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 certain countries' 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 or 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 LAM 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.

Already, LAM 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 LAM countries 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 planned policies/practices and national-level NDC targets for ten selected Latin American ("LAM") countries—Argentina, Brazil, Chile, Colombia, Ecuador, Mexico, Panama, Peru, Uruguay, and Venezuela—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 covers both larger and smaller Latin American economies and clearly documents the data and assumptions associated with our calculations of the future emission trajectories (the "Policy scenario") and 2030 NDC targets. Simple GAMS-based tool is available (upon request) that tracks every LAM country. This available tool provides an opportunity for an independent verification and a sensitivity analysis for the Policy scenario input assumptions and for further improvement of the assessment.

The LAM countries face the challenge of reducing greenhouse gas (GHG) emissions while at the same time expanding energy supply to meet the needs of growing economies. The LAM region is an important contributor to global development (see Figure 1.1). In 2010, its population accounted for about 7.2% of the global population (UN, 2017) and 8% 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 LAM region's global share in 2010 was about 6% (IEA, 2017c).[1]

GHG emissions related to land-use, land-use change, and forestry (LULUCF) are substantial for the LAM region, but they are known with less certainty than energy and industrial emissions. According to IEA (2017c), the LAM region's LULUCF emissions are about 12% 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 LAM. 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

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[1] Of Latin America in its entirety, the ten countries in LAM represent about 84% of the population, 93% of GDP PPP, and 90% of GHG emissions in 2010.

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 LAM countries. Where applicable, in this report we follow UNFCCC data and country reported statistics (see Figure 1.3).

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 LAM region is projected to have modest growth in energy demand—approximately a 25% increase in total primary energy supply from 2015 to 2030—due to an expanding population and economy. Continued progress 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 LAM countries for the Paris Agreement process. Section 3 provides our projections for LAM 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: Argentina and Colombia. 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.

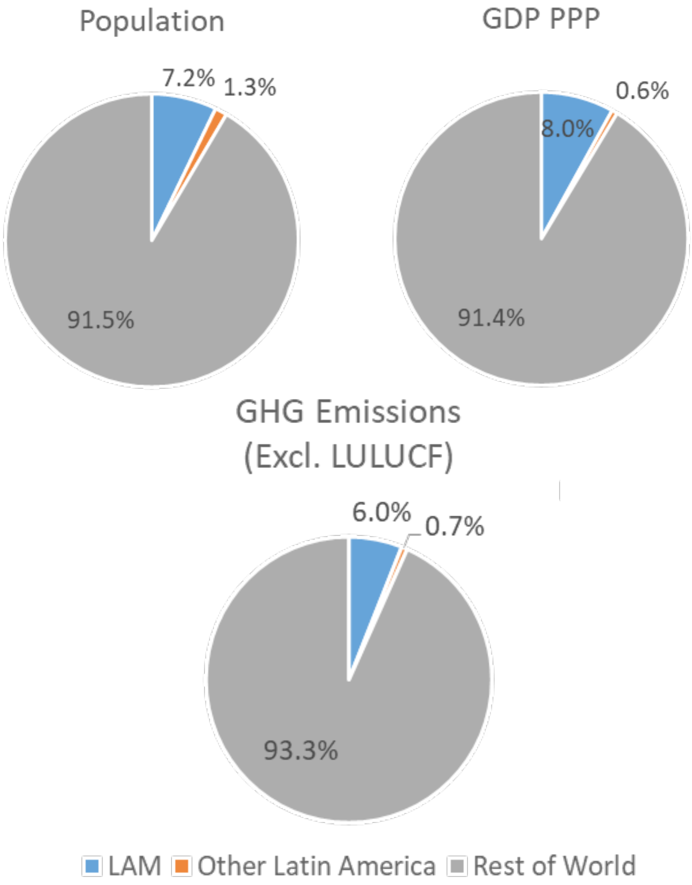

Figure 1.1. LAM's shares in global population, GDP, and GHG emissions

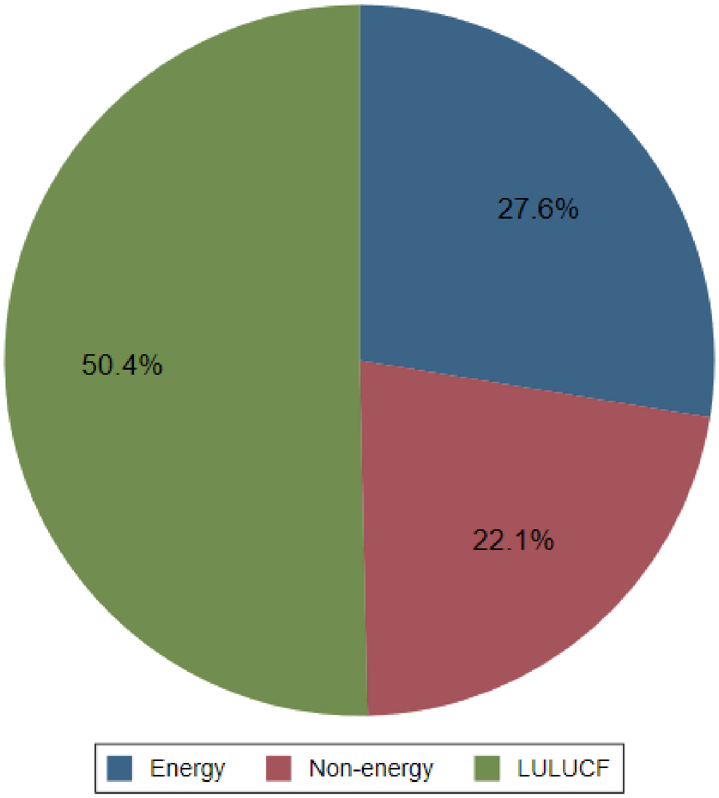

Figure 1.2. LAM's GHG emissions in 2010 by sector (energy, non-energy, and LULUCF)

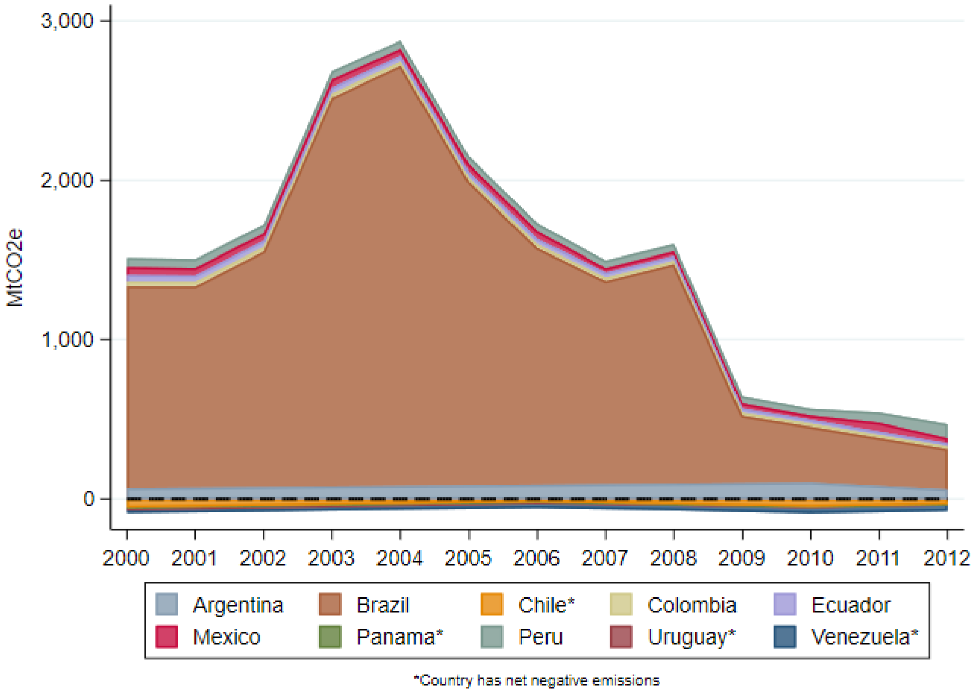

Figure 1.3. LAM's LULUCF emissions for 2000, 2005, and 2010.

2 Pledges of the LAM Countries for the Paris Agreement Process

Main Takeaways

- GHG emissions in the LAM region are projected to increase from about 3,200 $MtCO_2e$ in 2015 to 3,631 $MtCO_2e$ in 2030 under a climate policy scenario. This emissions trajectory is notably lower than in a business-as-usual scenario and reflects the LAM countries' planned expansion of renewables and natural gas in their electricity generation portfolios.
- 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 3,569 $MtCO_2e$. Consequently, the emissions gap is 62 $MtCO_2e$, which indicates that, in aggregate, the LAM region will have to reduce their emissions by 2% relative to the Policy scenario to achieve their NDC pledges. Under the conditional emissions target (about 3,284 $MtCO_2e$), the emissions gap is 347 $MtCO_2e$, which indicates a needed reduction of 10% relative to the Policy scenario emissions.
- Individually, while some countries are projected to be close to or to even over-achieve their unconditional and conditional goals for 2030, others require additional efforts. While some LAM countries face the challenge of developing stable regulatory and legal frameworks to further encourage private investments in clean energy projects, there are many policy and technology options available to them to reduce 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 LAM countries is provided in Table 2.1. The left-hand columns lists our estimates of the business-as-usual ("Baseline scenario") and policy scenario ("Policy scenario," based on announced energy supply and generation plans) emissions in 2030. The middle columns report 2030 emissions consistent with conditional and unconditional pledges. The right-hand columns report the emissions gap (i.e., the volume of reductions to be achieved under a specific target) for each country in 2030, measured as Policy 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 LAM region has a small emissions gap in meeting its Paris goals. In 2030, the estimated Policy scenario emissions are 3,631 million tonnes of CO_2-equivalent ($MtCO_2e$). Using the Baseline scenario trajectory[1], the unconditional emissions target is calculated as 3,569 $MtCO_2e$. Consequently, the emissions gap is 62 $MtCO_2e$, which indicates that, in aggregate, the LAM region will have to reduce its emissions by an additional 2% relative to the Policy scenario to meet its countries' unconditional NDC pledges. Under the conditional emissions target (3,284 $MtCO_2e$), the emissions gap is 347 $MtCO_2e$, which indicates a needed reduction of 10% relative to the Policy 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 Policy scenario emissions while bubble size is proportional to country Policy emissions. Note that Panama and Venezuela are excluded from Figure 2.1 as these two countries do not declare unconditional targets.

As shown in Figure 2.3, LAM emissions are expected to grow gradually with the Policy trajectory, and the gap from Paris Agreement pledges represents a small remaining decrease in emissions. As illustrated in Figure 2.4, emissions growth in the LAM 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	By	Relative to	Emissions ($MtCO_2e$)	Emissions ($MtCO_2e$)	%
Argentina	459	UC[†]	483 $MtCO_2e$ - Total emissions cap	2030		483	-24	-5%
		C[*]	369 $MtCO_2e$ - Total emissions cap	2030		369	90	20%
Brazil	1,468	UC	43% - emissions	2030	2005	1,692	-224	-15%
		C	Same as UC	2030	Same as UC	1,692	-224	-15%
Chile	128	UC	30% - emissions intensity of GDP	2030	2007	136	-8	-6%
		C	35% - emissions intensity of GDP	2030	2007	126	2	2%
Colombia	183	UC	14% - emissions	2030	Baseline	169	14	8%
		C	27% - emissions	2030	Baseline	144	40	22%
Ecuador	85	UC	20.4% - energy emissions	2025	Baseline	69	16	19%
		C	37.5% - energy emissions	2025	Baseline	54	31	36%
Mexico	789	UC	18% - emissions	2030	Baseline	757	32	4%
		C	32% - emissions	2030	Baseline	628	161	20%
Panama	19	UC	Baseline			23	--	--
		C	Renewables generation +15 % pts	2030	2014	22.8	-4	-20%
Peru	137	UC	20% - emissions	2030	Baseline	139	-2	-1%
		C	30% - emissions	2030	Baseline	133	4	3%
Uruguay	53	UC	27%/62%/51% - $CO_2/CH_4/N_2O$ emissions int. of GDP	2030	1990	54	0	-1%
		C	31%/63%/57% - $CO_2/CH_4/N_2O$ emissions int. of GDP	2030	1990	51	3	5%
Venezuela	309	UC	Baseline			366	--	--
		C	20% - emissions	2030	Baseline	293	16	5%
LAM	**3,631**	**UC**	**--**			**3,569**	**62**	**2%**
		C	**--**			**3,284**	**347**	**10%**

[†]Unconditional [*]Conditional

Note: Estimates exclude LULUCF-related emissions. LAM totals exclude negative emissions gaps in individual countries. Additionally, country emissions may not sum to the LAM totals due to rounding.

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[1] Yields 4,0119 $MtCO_2e$ in 2030.

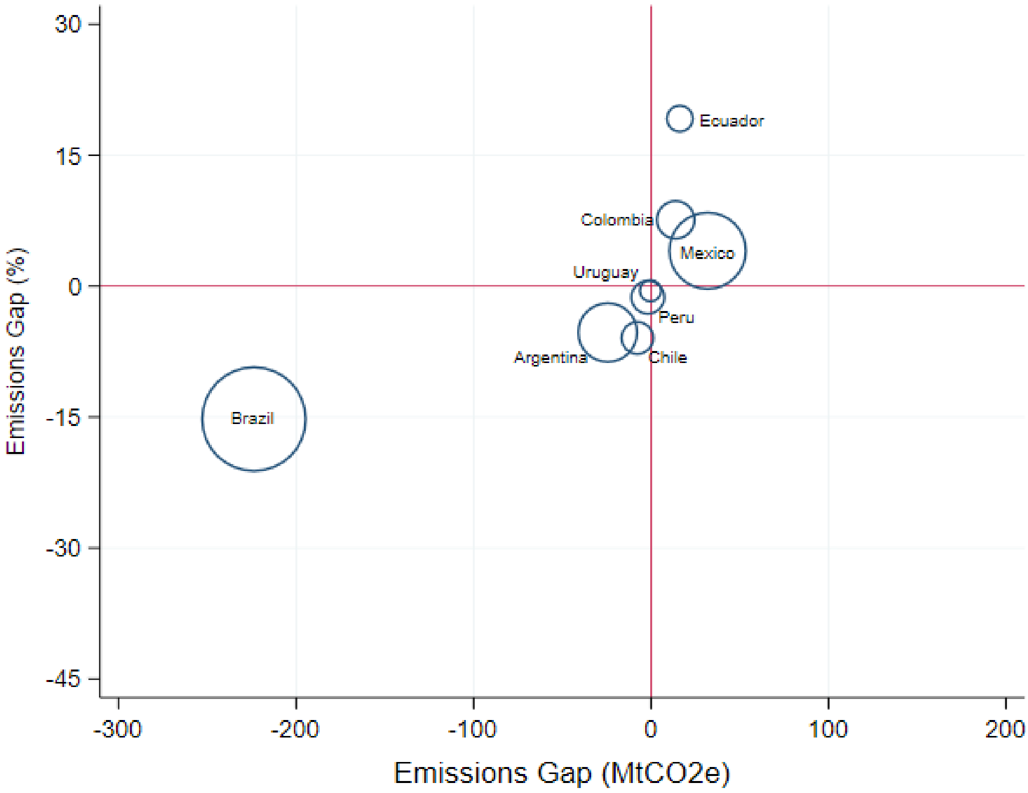

Figure 2.1. LAM countries' absolute (MtCO$_2$e) and relative (percent of Policy) targeted emissions gap in 2030 under unconditional pledges. The bubble sizes are proportional to country Policy emissions.

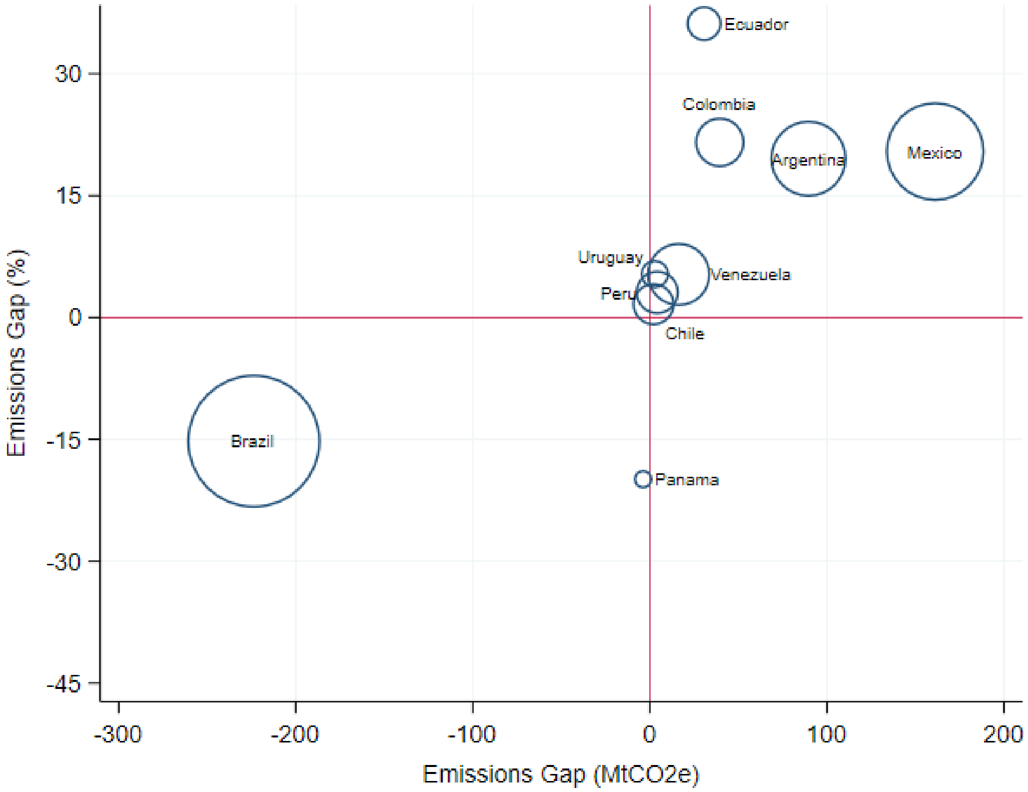

Figure 2.2. LAM countries' absolute (MtCO$_2$e) and relative (percent of Policy) targeted emissions gap in 2030 under conditional pledges. The bubble sizes are proportional to country Policy emissions.

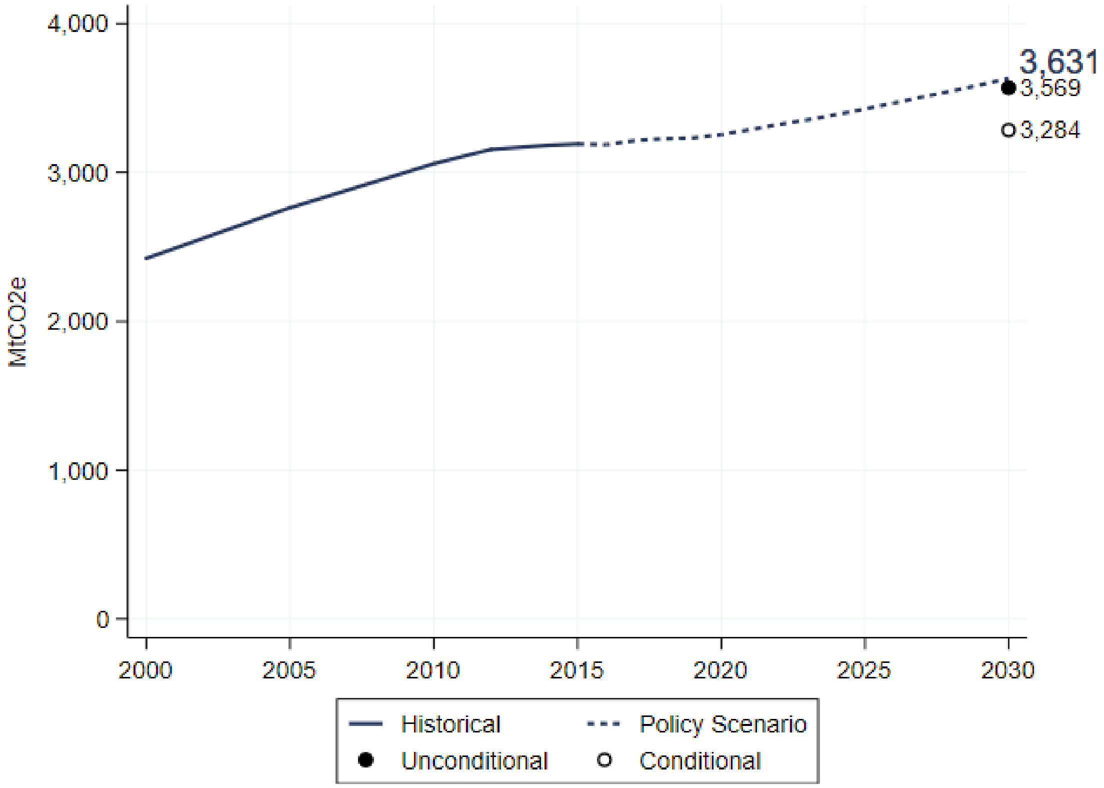

Figure 2.3. LAM's GHG emissions in 2000-2030 (excluding LULUCF) in the Policy scenario and the estimated unconditional emission target (full circle) and conditional emission target (empty circle).

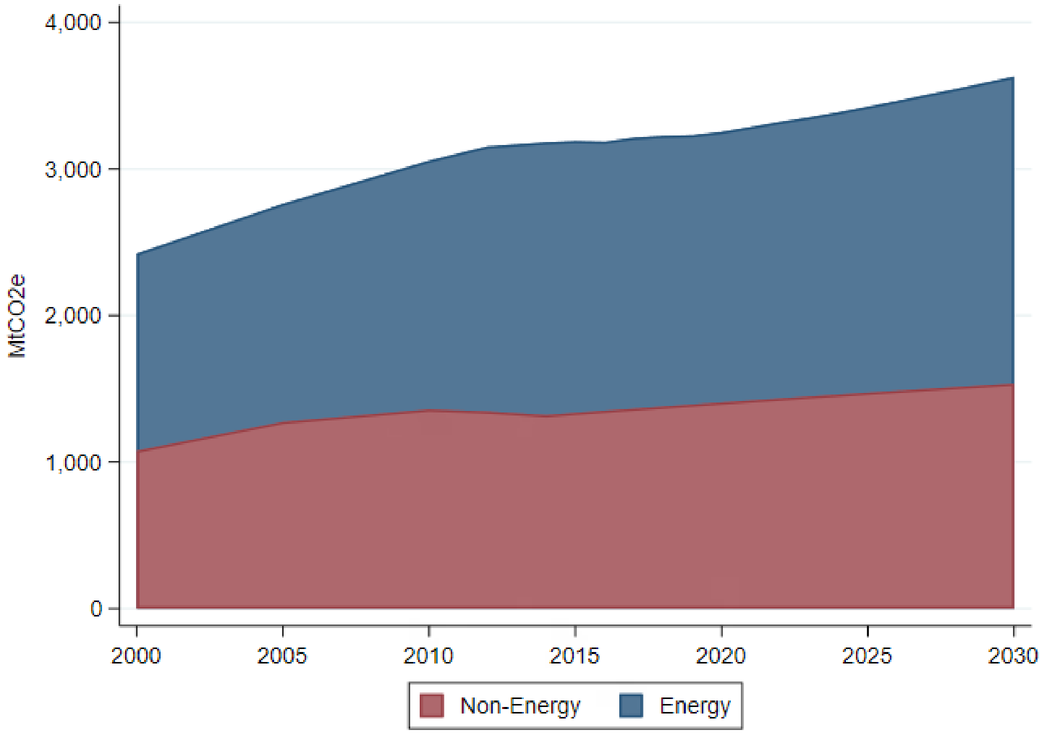

Figure 2.4. LAM's GHG emissions in 2000-2030 (excluding LULUCF) by energy and non-energy contributions in the Policy scenario.

3 Projected LAM Energy and Electricity Profiles to 2030

Main Takeaways

- The LAM region is growing steadily in its energy and electricity consumption. From 2015 to 2030 primary energy supply is projected to grow by 23% while electricity generation is projected to grow by 37%.
- Solar and wind generation in the LAM region is expected to grow about 550% between 2015 and 2030 while generation from fossil fuels will decrease by 3%. As a result, the share of electricity generated from fossil fuels will decrease from 45% in 2015 to 31% in 2030.
- We project that the main components of the LAM primary energy supply in 2030 will be oil (41% of total primary energy), natural gas (24%), and biofuels (17%). For electricity, the main sources of generation in 2030 are projected to be hydro (45% of total generation); natural gas (26%); and unconventional renewables such as wind and solar (15%).
- The three largest energy consumers in LAM—Brazil, Mexico, and Argentina—together account for about 75% of both the regional primary energy and electricity generation in 2030.
- The LAM countries show a wide range of electricity generation per capita in 2030, from 2.04 MWh per capita in Colombia to 5.67 MWh per capita in Uruguay. 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 LAMs primary energy supply in 2030: 41% oil, 24% natural gas, and 17% biofuels.

Energy use grows gradually in the LAM 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 LAM TPES will grow by 23% from 756 million tonnes of oil equivalent (Mtoe) in 2015 (IEA, 2017a) to 932 Mtoe in 2030 consisting of 41% oil; 24% natural gas; 17% biofuels and waste; 8% hydro; 4% an aggregate of wind, solar, and geothermal; 3% coal; and 2% nuclear (Figure 3.1). Overall, these fuel shares remain quite steady from 2015 to 2030, with the gradual growth in total energy supply driven by small increases in biofuels for transportation and combined heat and power generation, and in other renewables (nuclear; hydro; and geothermal, solar, and wind) for electricity generation. Although oil and natural gas together make up of 65% TPES in 2030, the share of oil in aggregate energy supply slightly decreases from 45% in 2015 to 31% in 2030 while the share of natural gas remains constant at about 26%.

Unconventional renewables like wind, solar, and geothermal in aggregate show rapid growth, increasing about 550% between 2015 and 2030.

We project electricity production[2] in the LAM region to grow by 37% from 1,409 terawatt hours (TWh) in 2015 (IEA, 2017a) to 1,934 TWh in 2030. The projected electricity growth is higher than the growth in TPES reflecting an increased electrification of energy use. Additionally, while primary energy relies mainly on fossil fuels, the majority of electricity comes from renewable sources, primarily hydro. Notably, unconventional renewables like wind, solar, and geothermal—while contributing to only 3% of generation in 2015—in aggregate show rapid growth, increasing about 550% between the years 2015 and 2030 to become a substantial contributor to the region's generation profile. Altogether, the electricity generation mix in 2030 is projected to be

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[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] We use the terms "electricity production" and "electricity generation" interchangeably.

of 45% hydro; 26% natural gas; 15% wind, solar, and geothermal; 5% nuclear; 5% biofuels and waste; 3% coal; and 2% oil (Figure 3.2).

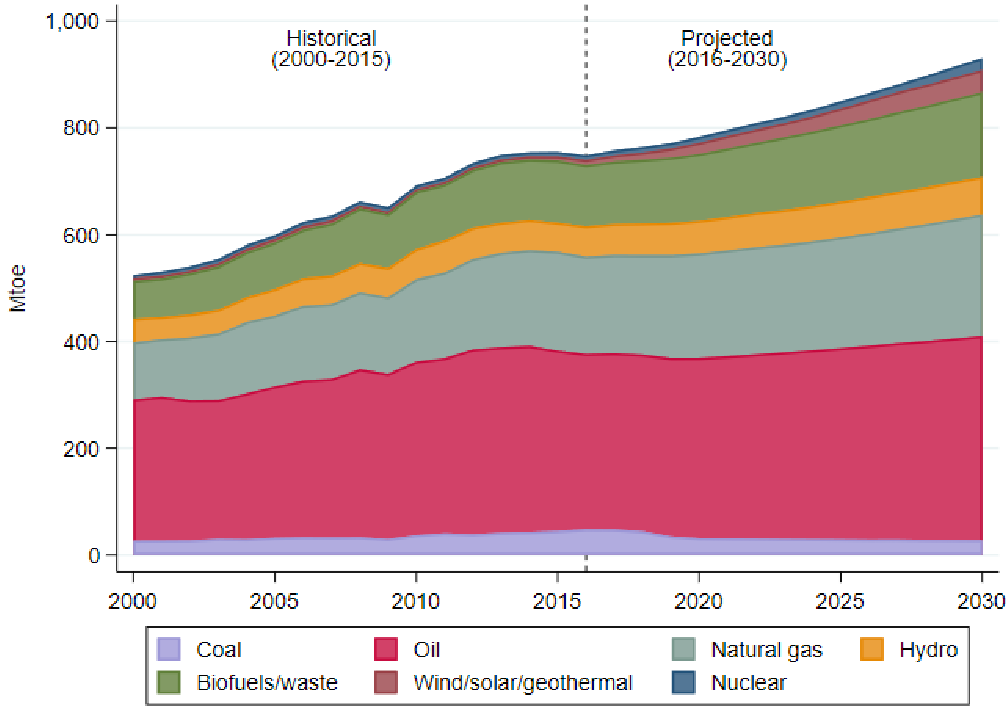

Figure 3.1. LAM Total Primary Energy Supply by Fuel Type.

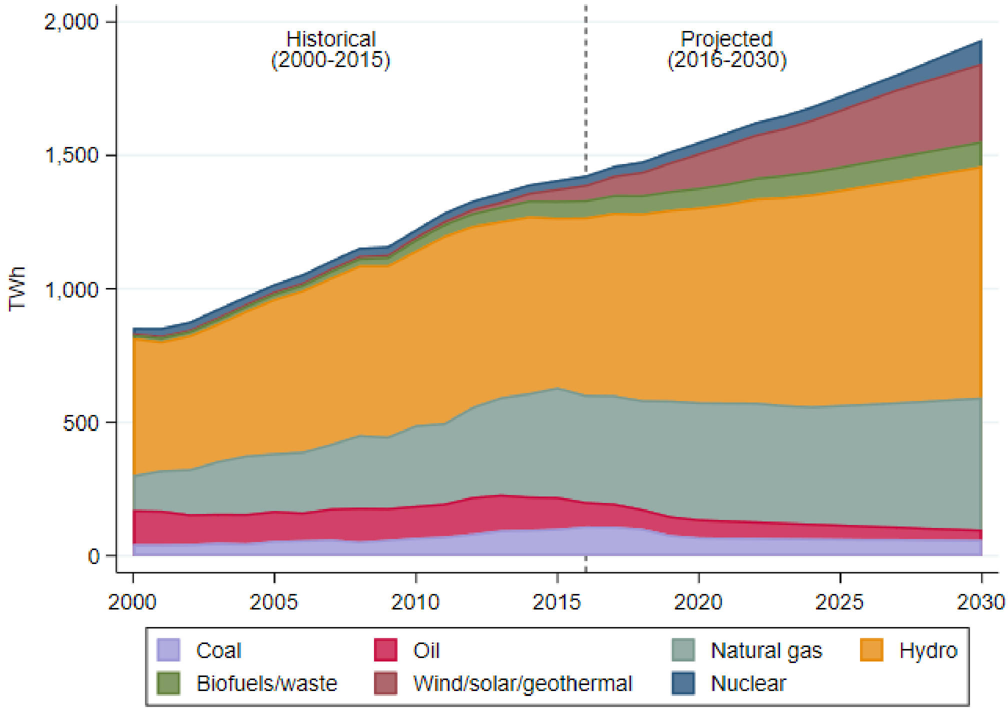

Figure 3.2. LAM Power Generation by Fuel Type.

Of the ten LAM countries analyzed, Brazil is the largest energy consumer, accounting for 40% of both the regional TPES (Figure 3.3) and 39% regional electricity generation (Figure 3.4) in 2030. The three largest energy consumers—Brazil (374 Mtoe and 754 TWh in 2030), Mexico (210 Mtoe and 444 TWh in 2030), and Argentina (109 Mtoe and 214 TWh in 2030), together account for 74% of regional TPES and 73% of electricity generation in 2030.

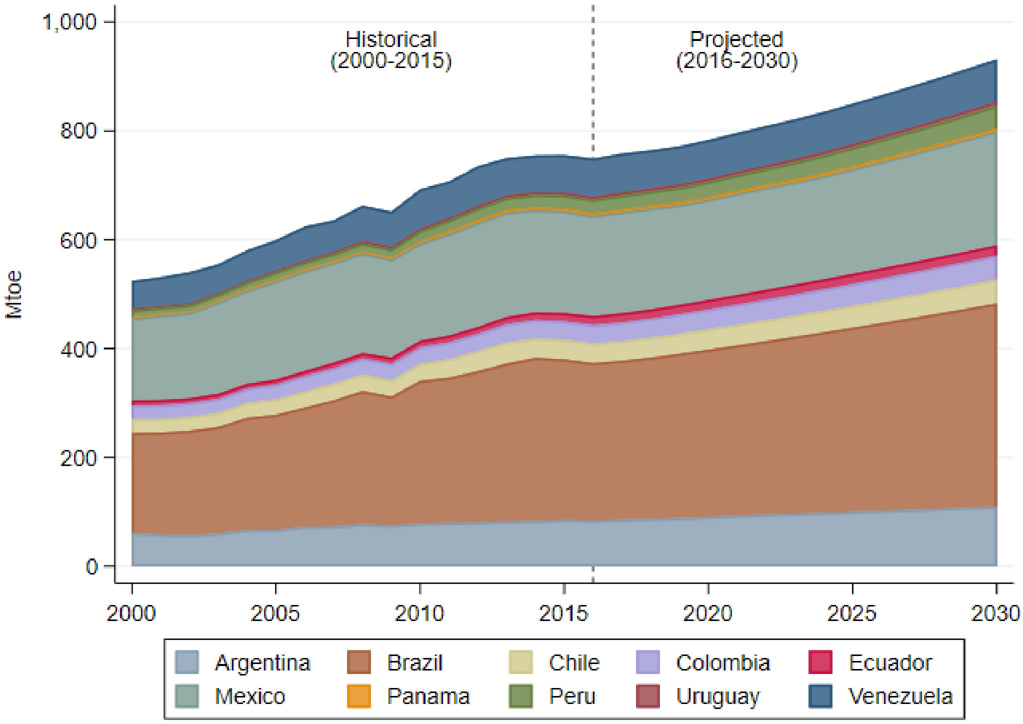

Figure 3.3. LAM Total Primary Energy Supply by Country.

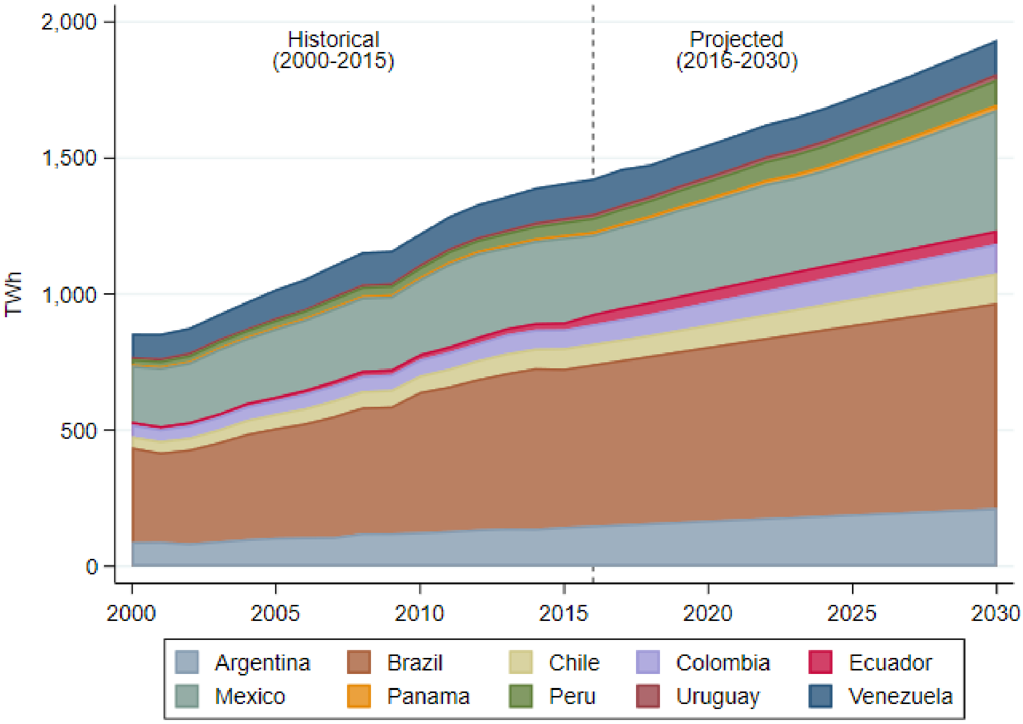

Figure 3.4. LAM Power Generation by Country.

A useful metric to gauge potential expansion in the power generation sector is 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 LAM countries, with the average annual growth rate in 2016-2030 ranging from 0.3% in Uruguay to 1.4% in Panama (Figures 3.5-3.6).

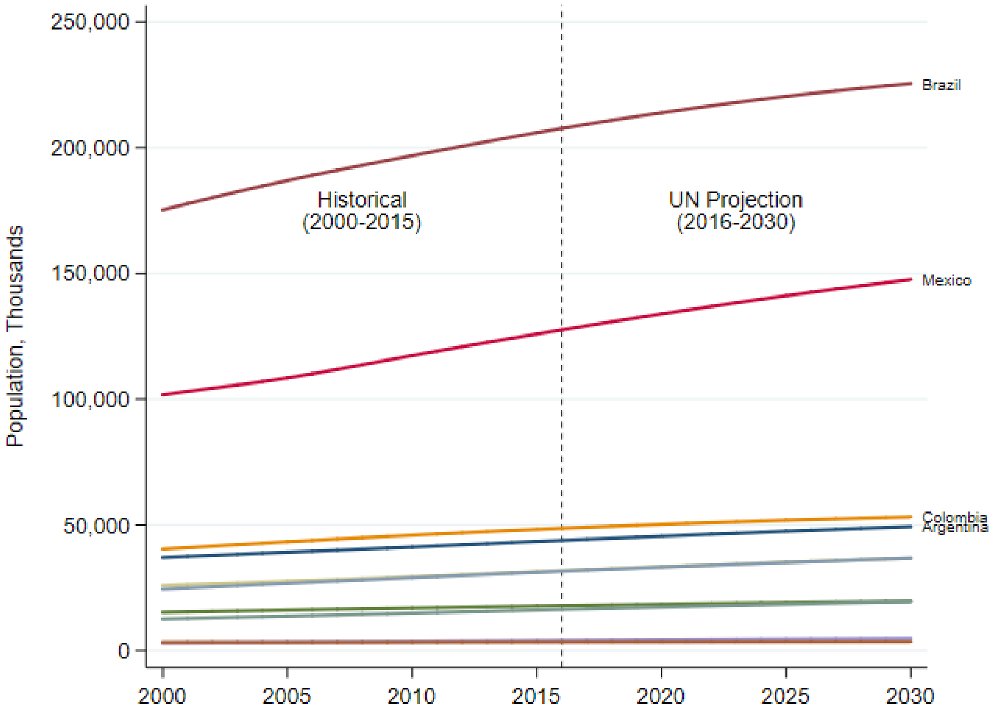

Figure 3.5. LAM countries population (all countries).

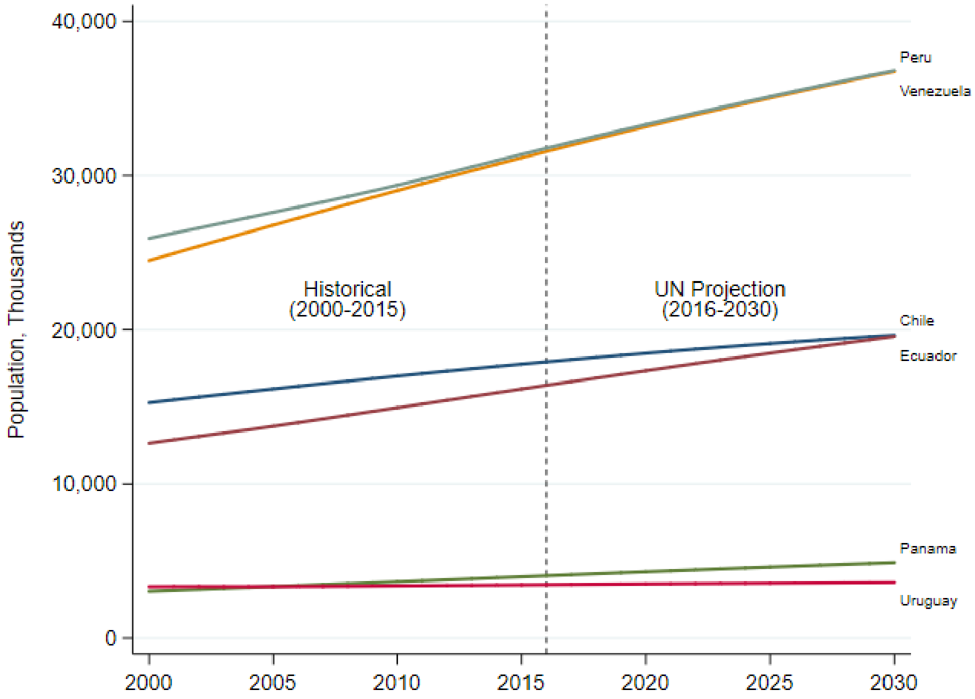

Figure 3.6. LAM countries population (smaller countries).

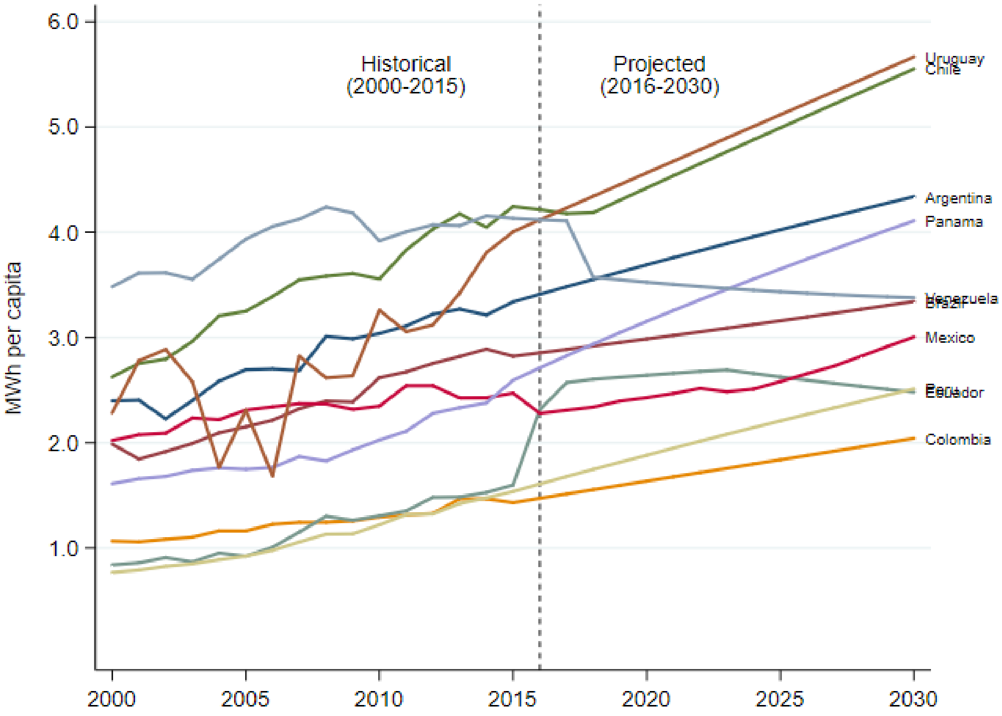

Figure 3.7. LAM power generation per capita.

4 Policy and Technology Options for LAM to Reduce Emissions

The LAM countries in their NDCs list numerous plans, policies, and strategies as the means of implementation of their emission reduction goals. 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 LAM 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 LAM countries regarding the use of specific instruments.

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.

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 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
		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
		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
	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
		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
		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
		Credits and rebates (production & investment tax credits, reduction in energy and other taxes)	
		Depreciation rules	
		Loan guarantees	
Suasive Instruments		Labeling and information	Can help overcome information asymmetries and influence consumer choices; causal effect difficult to measure
		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
		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
		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?

4.1.2.2 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.[1] 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-

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[1] 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.

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

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.

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 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.

In summary, an advanced and well-designed electricity market, combined with advanced digitalization technologies (see below, 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.)

4.2 Recommendations for Policy Options

Main Takeaways

- For the LAM 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.

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.

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 these 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, constitutional or statutory property rights, or state contracts and transparent dispute settlement procedures guaranteeing the rights of investors, are a key factor determining the ability of countries to attract clean energy investment.

Currently, electricity market designs are again facing substantial pressure to transform. Emergence of disruptive technologies, such as distributed energy resources, energy storage, and digitalization, coupled with ever more stringent environmental policy requirements, are fundamentally changing the landscape in which energy markets operate. Design of electricity markets, for instance, needs to facilitate the integration of all 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, for instance via 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 and to better integrate intermittent and distributed resources .

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. Some LAM countries are already well into the subsidy removal process. Chile, for example, has removed almost all of its energy sector subsides, with the exception of a measure supporting low income households in the event of an electricity price spike. The country otherwise avoids government intervention in electricity pricing and has 100% private participation in generation, transmission, and distribution (Marchán *et al*., 2017).

For the LAM 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. These instruments are particularly suitable for countries with substantial experience with market-based mechanisms and competitive electricity markets. Already, a handful of LAM countries (Argentina, Chile, Colombia, and Mexico) have implemented targeted carbon prices in some sectors, and interest in this highly cost-effective and scalable policy option is high with several LAM countries considering adoption of a carbon tax or an ETS as part of their national strategies. International experience with such markets is extensive (for an overview of experience, see Section 7.3 of the report).

Several LAM countries have already implemented targeted carbon prices in some sectors, and several others are considering adoption of a carbon tax or an ETS as part of their national strategies.

For countries where a carbon tax or ETS is not currently feasible, we recommend an initial focus on technology-specific policies such as renewable energy auctions and renewable portfolio standards. 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. In Uruguay, for example, a $5.68 billion renewables investment program and reverse auction increased wind and solar output nearly twenty-fold from 2011 to 2015 and pushed the country to around 95% of generation from renewables by 2015 (Goldwyn and Clabough, 2018; IEA, 2017a). 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.

In the medium-term, enhancement of natural gas infrastructure could enable higher penetration of intermittent renewables by serving as backup capacity. 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 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., China, Egypt, and in LAM, Mexico) 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.

In any country, a policy package with one clear core policy instrument and complimentary 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. This 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.

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.

Further progress towards emission mitigation goals can be achieved by a reduction and eventual elimination of fossil fuel subsidies. Although fossil fuel prices in most LAM countries fluctuate based on prices in international markets, they remain regulated and are not fully liberalized. As electricity demand is growing in LAM countries, a reform in electricity subsidies 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 energy subsidies in Chile, reducing electricity subsidies in Argentina, and reforming discretionary electricity pricing mechanisms in Mexico), 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, enhancement of natural gas infrastructure enables higher penetration of intermittent renewables by serving as backup capacity.
- Wind and solar in the LAM 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 LAM 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 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 Argentina and Colombia 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 LAM countries, recognizing heterogeneity of the economies and current utilization of technologies. The list of technology options for the power generation sector is extensive. We categorize the options into five groups, summarized in 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. 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 can serve as backup capacity for countries pursuing intermittent renewables but that locks in 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 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, battery energy storage, virtual power plants, microgrids, tools for better citing and forecasting of wind and solar farms to maximize their utilization).

Beyond *Tiers I-III*, 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[2]. 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.

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,

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[2] While several LAM countries use biomass and waste to energy conversion, sustainability and scalability of these options are an area of further investigations.

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, 2016), which again calls for more sophisticated regulatory models that encourage flexibility and integrated planning.

Major shifts in a choice of generating technology move the LAM 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. 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.

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. 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. 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. Meanwhile, natural gas provides a viable alternative to manage the intermittency of renewable options. 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 Policy scenario trajectories and NDC pledges for each LAM country. We perform this analysis by (1) projecting each country's Baseline emissions based on historical energy, economic, and emissions data; (2) using the Baseline scenario (where applicable) to translate each country's NDC commitments into economy-wide emission targets; (3) constructing a Policy scenario for each country based on published energy supply plans; and (4) calculate the emissions gap as the difference in GHG emissions between the Policy 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 using the historical, average annual growth rate in energy intensity of GDP from 2000 to 2015, 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 IEA (2017c), 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 IEA (2017c) 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.

We modify the Baseline scenarios for each country to form a Policy scenario based on published generation and energy supply plans. Country-specific modeling information is provided in the individual country sections.

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.[1] By preserving transparency in our work, we hope to encourage further collaboration between the LAM countries and international community in estimating, measuring, and ultimately achieving NDC targets.

Countries are reviewed in alphabetical order. 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 GHG emissions by sector and gas is provided in Appendix D.

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[1] MIT researchers convened with government representatives of nine Latin American countries (of which seven are included in this report) in Buenos Aires in December 2017.

5.1 Argentina

Figure 5.1.1. Map of Argentina

Argentina is a large nation in the southern half of South America. It is bordered by Chile to the south and west; Bolivia and Paraguay to the north; and Brazil, Uruguay, and the Atlantic Ocean to the east. Argentina's capital city, Buenos Aires, is situated along the shore of the Río de la Plata, which flows eastward into the Atlantic Ocean.

According to UN (2017), Argentina had a population of 43.4 million people in 2015, or 8.29% of the total population in the LAM region. Argentina's population grew an average of 1.06 % annually from 2000 to 2015 (compared to the LAM rate of 1.24%) and is projected to grow at an average annual rate of 0.85% from 2016 through 2030 (compared to the LAM rate of 0.83%).

In 2015 the GDP of Argentina was 721 billion Argentine pesos (2004 prices). The country experienced an average annual growth rate of 2.75% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 2.34% average annual growth rate of GDP for 2016 to 2030.

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

In its Energy Scenarios 2030 report, Argentina assembles multiple energy production and consumption goals for 2030 based on high and low oil production and energy demand (MINEM, 2017). We model the "Trend+Investment" scenario with high prices and high demand as Argentina's climate policy trajectory. In the Trend+Investment scenario, electricity generation reaches 214,000 GWh in 2030 with 38% natural gas, 13% nuclear, 24% hydro, and 24%

unconventional renewables such as wind, solar, and bioenergy. Growth in hydropower is in part supported by the development of a 1,740 MW complex in Patagonia (IHA, 2018). Argentina is also aiming for 20% of its generation in 2025 to come from other renewable sources, per Law 27.191 and supported by its "RenovAR" renewable energy auction. Our modeling of this generation mix yields 109,230 ktoe of TPES consisting of 49% natural gas, 32% oil, 7% nuclear, 4% hydro, 4% biofuels/waste, and 4% other renewables. In comparison, Argentina's "Trend+Investment" scenario targets 117,000 ktoe of total internal energy supply, which is the primary energy supply plus the effect of the secondary energy trade balance. In a scenario with energy-efficient usage, Argentina expects total internal energy supply to decrease a further 12,000 ktoe.

Argentina is also aiming for 20% of its generation in 2025 to come from other renewable sources, per Law 27.191 and supported by its "RenovAR" renewable energy auction.

In the Policy scenario, Argentina is projected to emit 459 MtCO$_2$e excluding LULUCF emissions in the year 2030, with emissions from fossil fuel combustion contributing 56% of total modeled emissions. In its NDC, Argentina pledges unconditionally to cap its economy-wide emissions (including LULUCF) at 483 MtCO$_2$e in 2030, or at 369 MtCO$_2$e conditional on international financial support. As these absolute targets are inclusive on LULUCF, we include in Figure 5.1.4 the economy-wide 2030 BAU emissions reported in Argentina's NDC for reference.

As a point of comparison, policy projections from Climate Action Tracker (CAT, 2017) yield 470 MtCO$_2$e in 2030 excluding LULUCF, which is comparable to MIT's Policy scenario emissions of 459 MtCO$_2$e. Additionally, CAT calculates that to be in line with its economy-wide NDC targets, emission targets excluding LULUCF in 2030 are 405 MtCO$_2$e unconditionally and 310 MtCO$_2$e conditionally, or a 14% unconditional and 34% conditional decrease from CAT's estimate of policy emissions in 2030. Both the CAT and MIT estimates suggest that Argentina's non-LULUCF emissions meet Argentina's official, unconditional, and economy-wide target of 483 MtCO$_2$e; however, the inclusion of LULUCF in the emissions trajectory may place Argentina above its targeted emissions absent other mitigation actions.

While Argentina does not cite mitigation policies in its NDC, the country does state its intention to also target the agriculture, forestry, transport, industry, and waste sectors to achieve it NDC pledges. Specifically, the government has developed three plans of actions targeting the energy, forestry, and transportation sectors with each plan sub-divided into intervention arms (e.g., "Energy Demand" and "Energy Supply" in the Energy plan), then mitigation themes (e.g., energy efficiency, renewable energy, combustibles, and generation-at-scale), and then specific actions. Altogether, the plans yield estimated mitigation levels of 77 MtCO$_2$e in Energy, 27 MtCO$_2$e in Forestry, 5.9 MtCO$_2$e in Transport for the year 2030, which combine to form the country-estimated 109 MtCO$_2$e of economy-wide reductions needed to meet Argentina's unconditional emissions cap of 483 MtCO$_2$e in 2030 (GNCC, 2017).

While Argentina does not cite mitigation policies in its NDC, the country does state its intention to also target the agriculture, forestry, transport, industry, and waste sectors to achieve it NDC pledges.

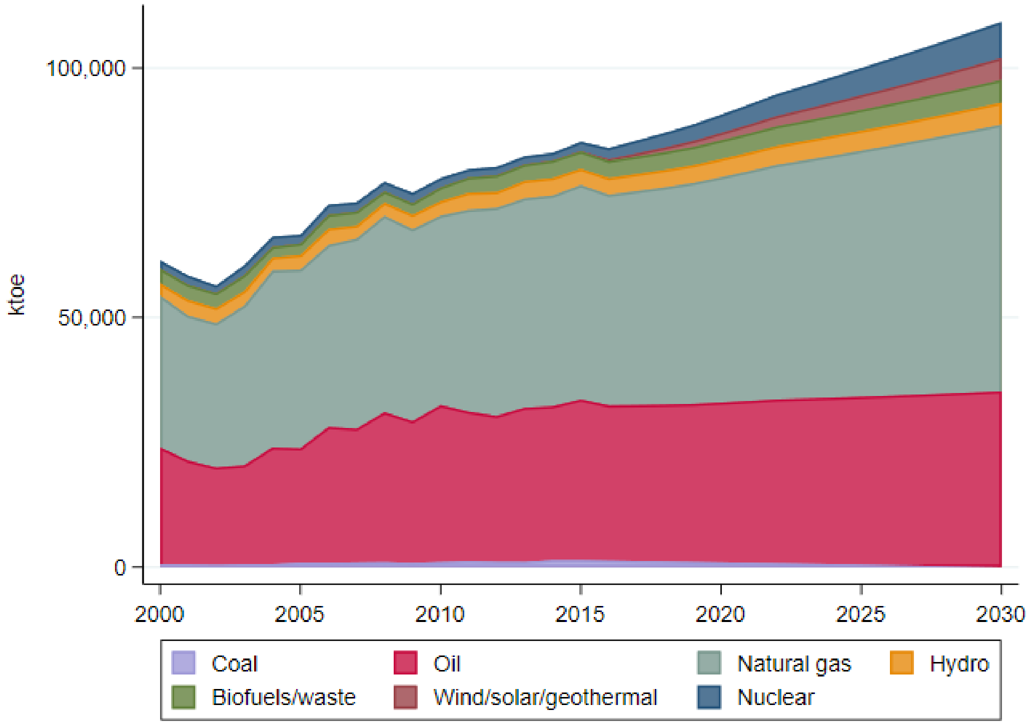

Figure 5.1.2. Argentina Total Primary Energy Supply (TPES)

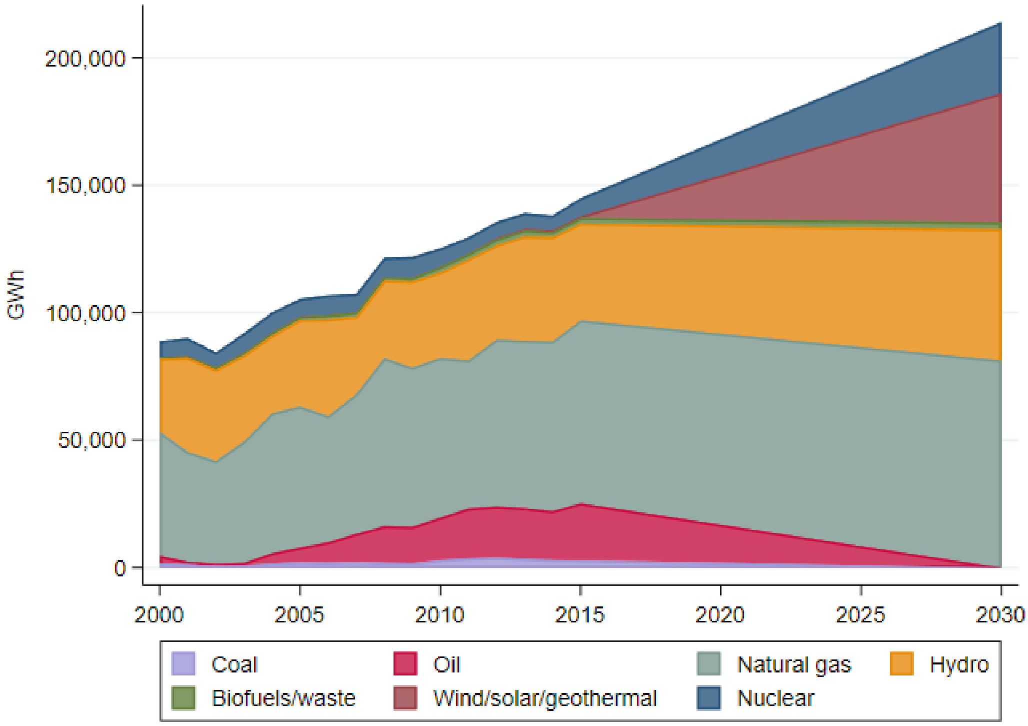

Figure 5.1.3. Argentina electricity generation

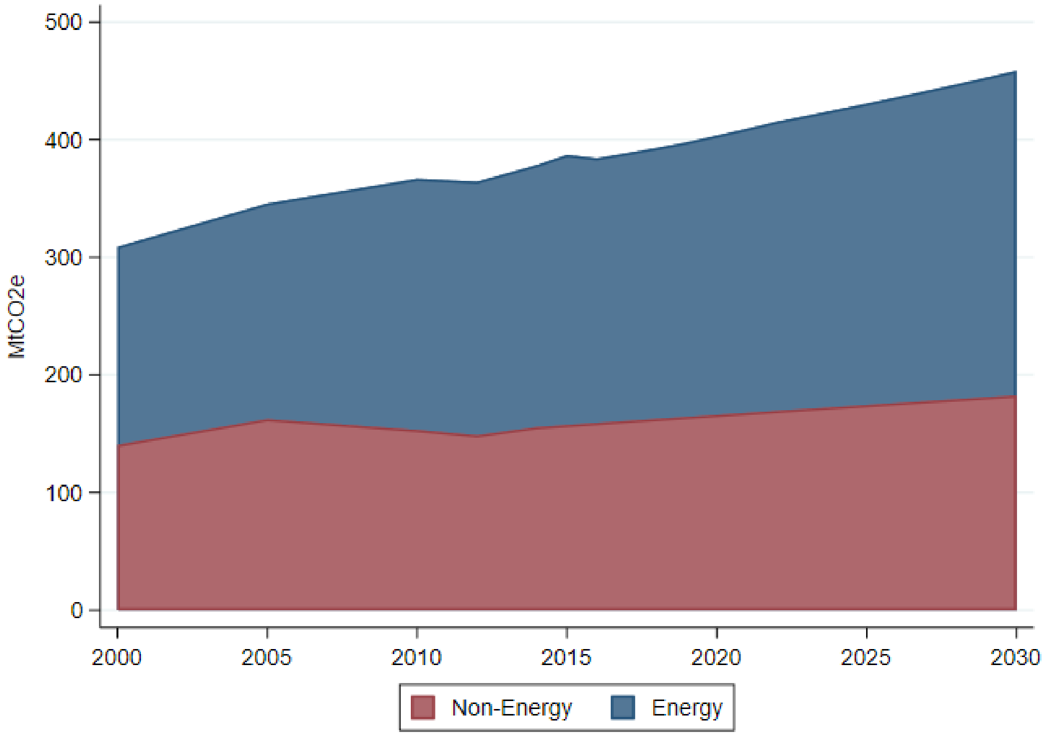

Figure 5.1.4. Argentina sectoral emissions

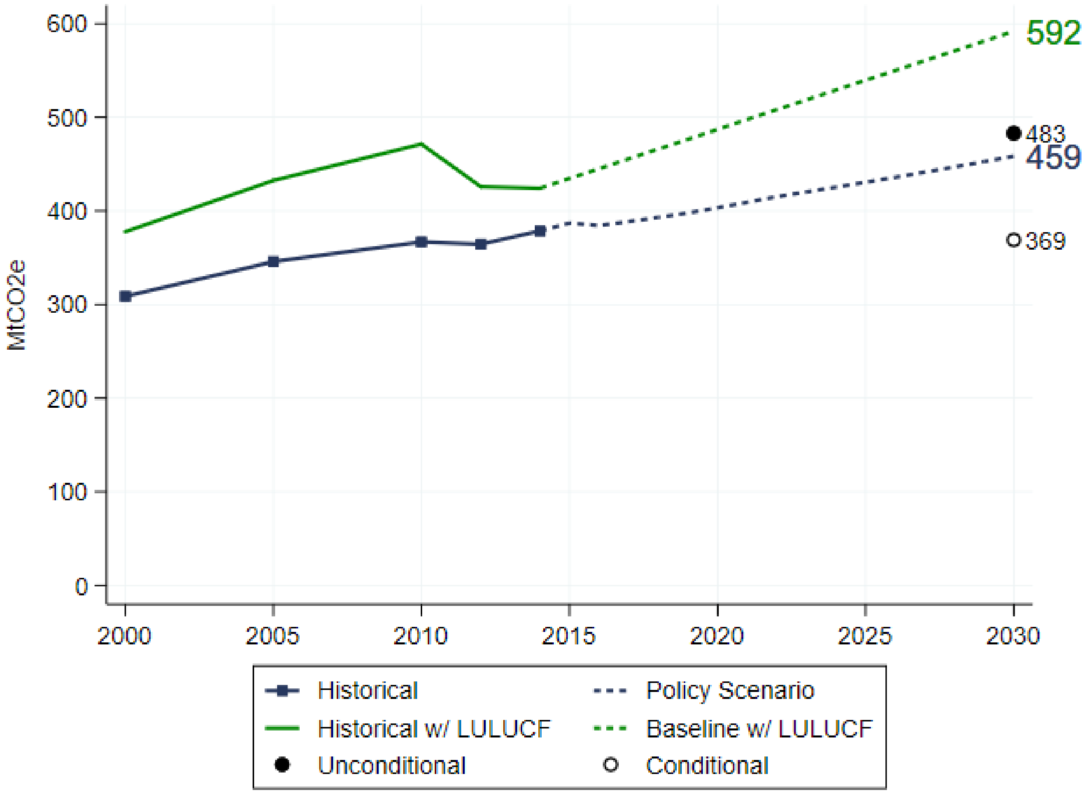

Figure 5.1.5. Argentina total emissions

Table 5.1.1. Fuel shares and generation ratios for Argentina

	Coal	Oil	Natural gas	Nuclear	Hydro	Wind/solar/ geothermal	Biofuels/ waste
2015: TPES Share	0.02	0.38	0.50	0.02	0.04	0.00	0.04
2015: Ratio - generation to TPES (GWh/ktoe)	2.12	0.69	1.67	3.84	11.63	11.63	0.61
Source: Calculations using IEA (2017a)							

Table 5.1.2. Projected growth rates for Argentina

	Average Annual Growth Rates
GDP (2016–2030)	2.34%
TPES per GDP (2016–2030)	-0.66%
Population (2016–2030)	0.85%

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

5.2 Brazil

Figure 5.2.1. Map of Brazil

Brazil is the fifth largest country in the world, both in terms of land area and population. Brazil is bordered by ten South American countries to the north, west, and south, and the Atlantic Ocean to the east. Four of Brazil's five most populous cities are located on its eastern coast while its populous capital city Brasilia is situated inland. The world's largest river basin, the Amazon River basin, runs through the northern portion of the Brazil and supports 5.5 million square kilometers of the Amazon rainforest.

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

According to UN (2017), Brazil had a population of 206 million people in 2015, or 39.3% of the total population in the LAM region. Brazil's population grew an average of 1.08% annually from 2000 to 2015 (compared to the LAM rate of 1.24%) and is projected to grow at an average annual rate of 0.61% from 2016 through 2030 (compared to the LAM rate of 0.83%).

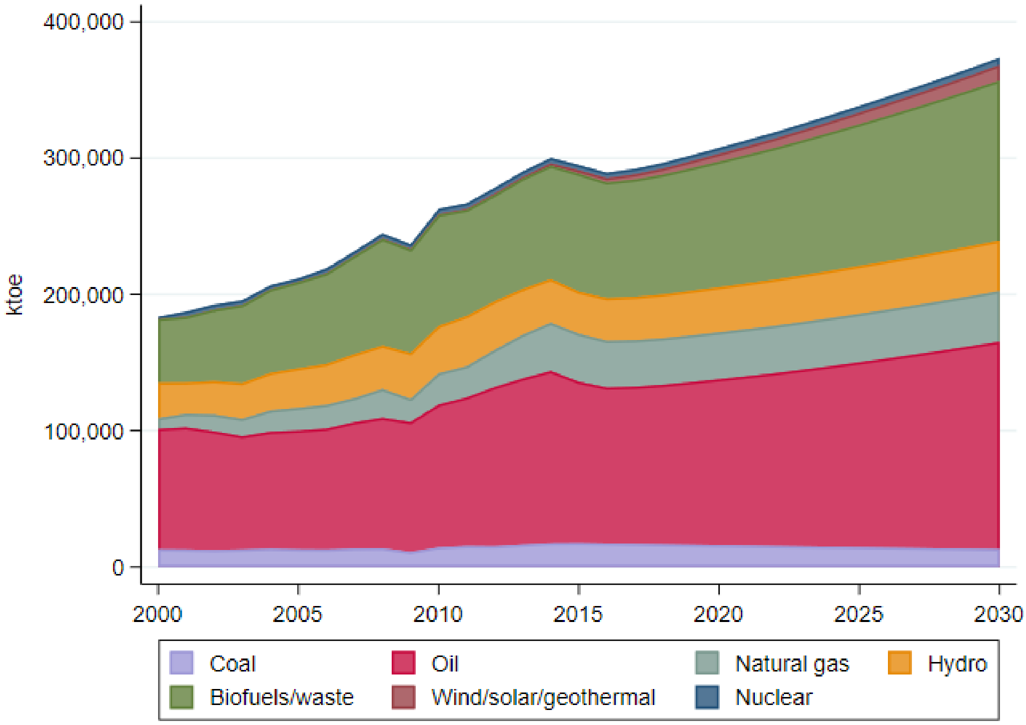

Figure 5.2.2. Brazil Total Primary Energy Supply (TPES)

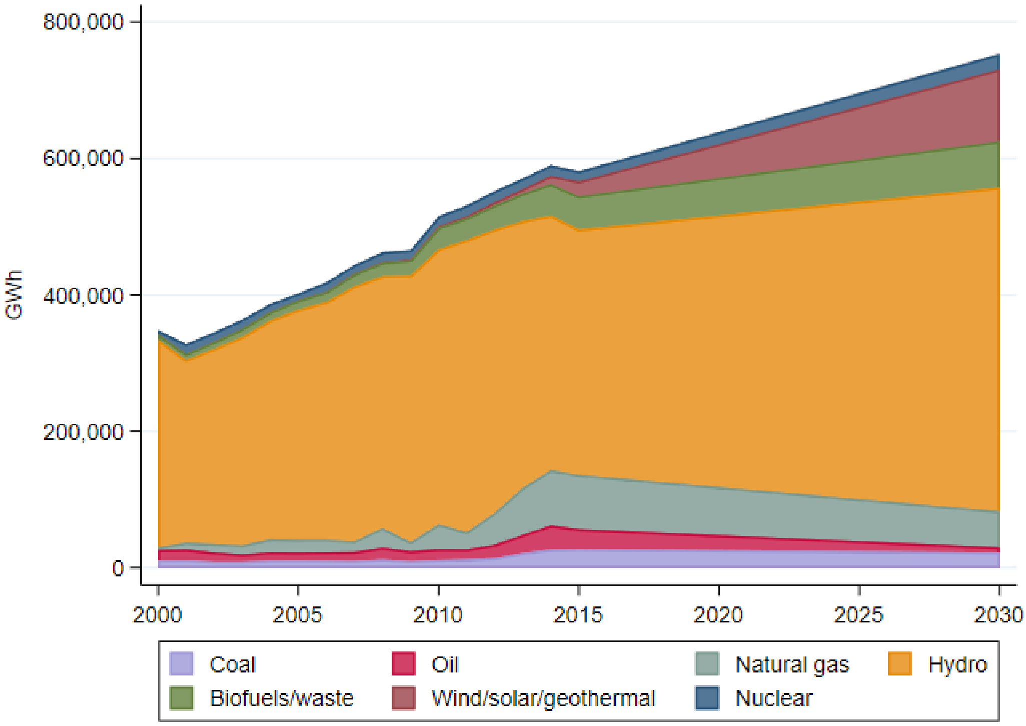

Figure 5.2.3. Brazil electricity generation

In 2015 the GDP of Brazil was 1.2 trillion Brazilian real (1995 prices). The country experienced an average annual growth rate of 2.81% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 1.62% average annual growth rate of GDP for 2016 to 2030.

Under the Policy scenario, TPES in Brazil reaches 373,662 ktoe in 2030 with a fuel makeup of 41% oil, 31% biofuels, 10% hydro, 10% natural gas, 4% coal, 3% wind/solar/geothermal, and 2% nuclear. Total generation in 2030 is 753,562 GWh with 63% hydro, 14% wind/solar/geothermal, 9% biofuels, 7% natural gas, 3% coal, 3% nuclear, and 1% oil. These projections reflect Brazil's targeted 10% increase in generation efficiency by 2030 and incorporate expansion plans for hydro, nuclear, and non-conventional renewable generation. Hydro capacity in Brazil was 100,273 MW in 2017 (IHA, 2018) and is expected to reach around 108,273 MW in 2019 as additional plants come online, including the final stages of the 11,200 MW Belo Monte project, which will become the third largest hydropower plant in the world when completed and fully operational in 2020. However, while additional possible projects have been identified, the Belo Monte hydropower plant will be Brazil's final mega project as the government begins favoring decentralized renewables (IHA, 2018). Therefore, we conservatively model a 1% expansion in hydropower from 2019 to 2030 yielding 119,601 MW of hydro capacity in 2030, or 478,365 GWh of hydro generation adopting Brazil's historical capacity factor of 46%. Nuclear power remains at 2-3% of the electricity mix in our projections though generation output increases from 14,734 GWh in 2015 to 24,580 GWh in 2030 based on the 1,405 MW Angra 3 project, currently on hold but anticipated post-2020. We also model an increased rate of expansion of geothermal, solar, wind, and bioenergy to capture Brazil's target of 23% of its generation in 2030 coming from other renewable sources.

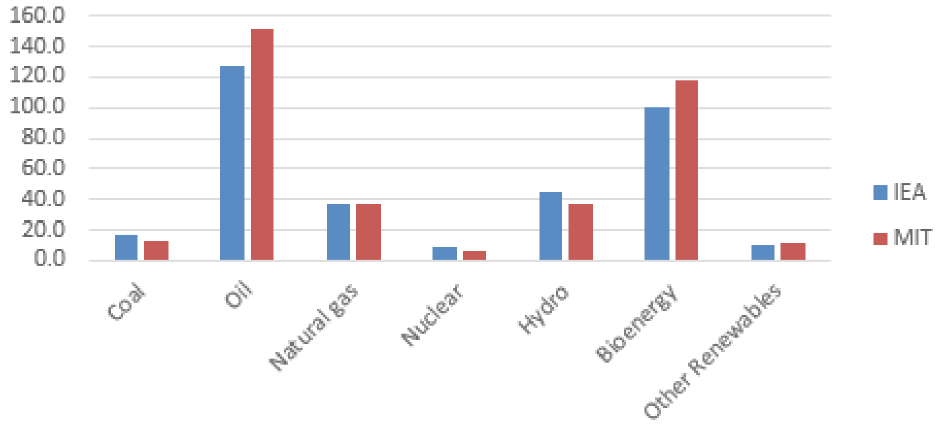

Figure 5.2.4. IEA (2017b) and MIT estimates of energy supply in Brazil in 2030

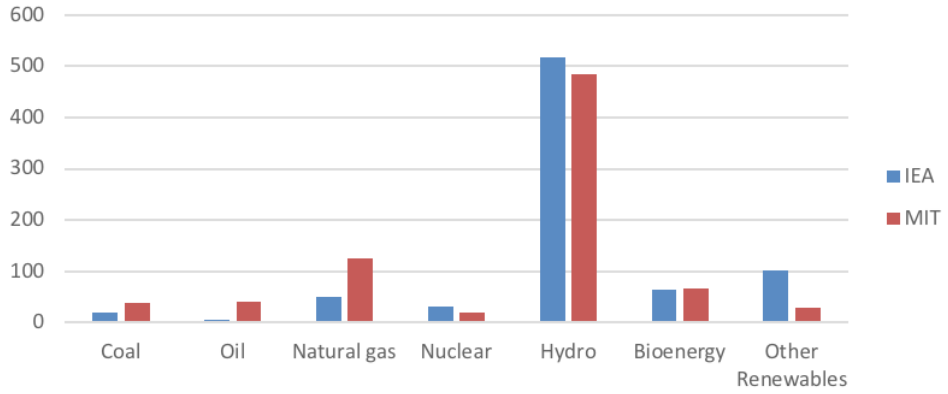

Figure 5.2.5. IEA (2017b) and MIT estimates of generation in Brazil in 2030

In comparison to MIT's estimates of a 2030 energy supply of 374 Mtoe and generation of 754 TWh, the 2017 IEA Energy Outlook projects an energy demand and generation level of 345 Mtoe and 790 TWh for Brazil in 2030 (IEA, 2017b) in the New Policies Scenario. Figures 5.2.4 and 5.2.5 compare MIT and IEA's energy supply and generation projections by fuel under climate policy. While results are similar, MIT more heavily represents oil and biofuels in Brazil's 2030 energy mix though both fuels have minor roles in electricity generation.

In the Policy scenario, Brazil is projected to emit 1,468 MtCO$_2$e excluding LULUCF emissions in the year 2030, with emissions from fossil fuel combustion contributing 46% of total modeled emissions. In its NDC, Brazil pledges unconditionally to reduce its economy-wide emissions by 37% in 2025 relative to 2005 emissions, which Brazil translates to an indicative target of a 43% reduction in 2030. Using base year emissions of 1,557 MtCO$_2$e in 2005[2] excluding LULUCF, we convert the 2030 indicative target into an emissions goal of 1,692 MtCO$_2$e. Therefore, the emissions trajectory in the Policy scenario yields an emissions gap of -224 MtCO$_2$e.

A substantial decrease in LULUCF emissions between 2005 to 2012 greatly reduced Brazil's economy-wide emissions, illustrated by the green line in Figure 5.2.7, and set the country on the path to meeting is Paris pledge. Notably, CAT (2018) estimates that as a result of anti-deforestation policies during this time frame, Brazil only needs to decrease its economy-wide emissions a further 7% below 2012 levels by 2030 to meet its targets. Therefore, as the MIT analysis excludes LULUCF, our results suggest that Brazil's ultimate achievement of its targets will in part depend on sustained success in its deforestation measures. Beyond the land use and energy sectors, Brazil's NDC also cites the enhanced adoption of energy efficiency measures and clean technology within the industry and transportation sectors as additional initiatives to bolster Brazil's emission mitigation efforts.

> *As a result of anti-deforestation policies between 2005–2012, Brazil only needs to decrease its economy-wide emissions a further 7% below 2012 levels by 2030 to meet its targets.*

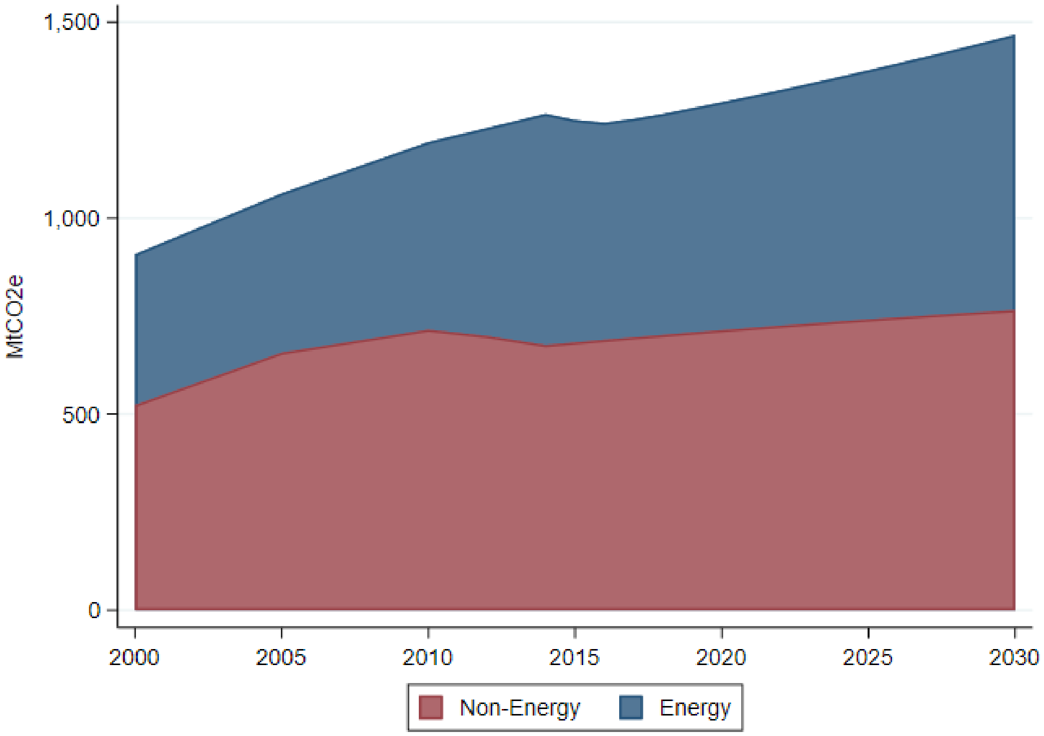

Figure 5.2.6. Brazil sectoral emissions

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[2] About 2,968 MtCO$_2$e including LULUCF. Note that Brazil used a smaller economy-wide emissions estimate for 2005 (2,043 MtCO$_2$e from its Second National Communication) to define its official NDC targets, which Brazil calculates as 1,328 MtCO$_2$e unconditionally and 1,164 MtCO$_2$e conditionally.

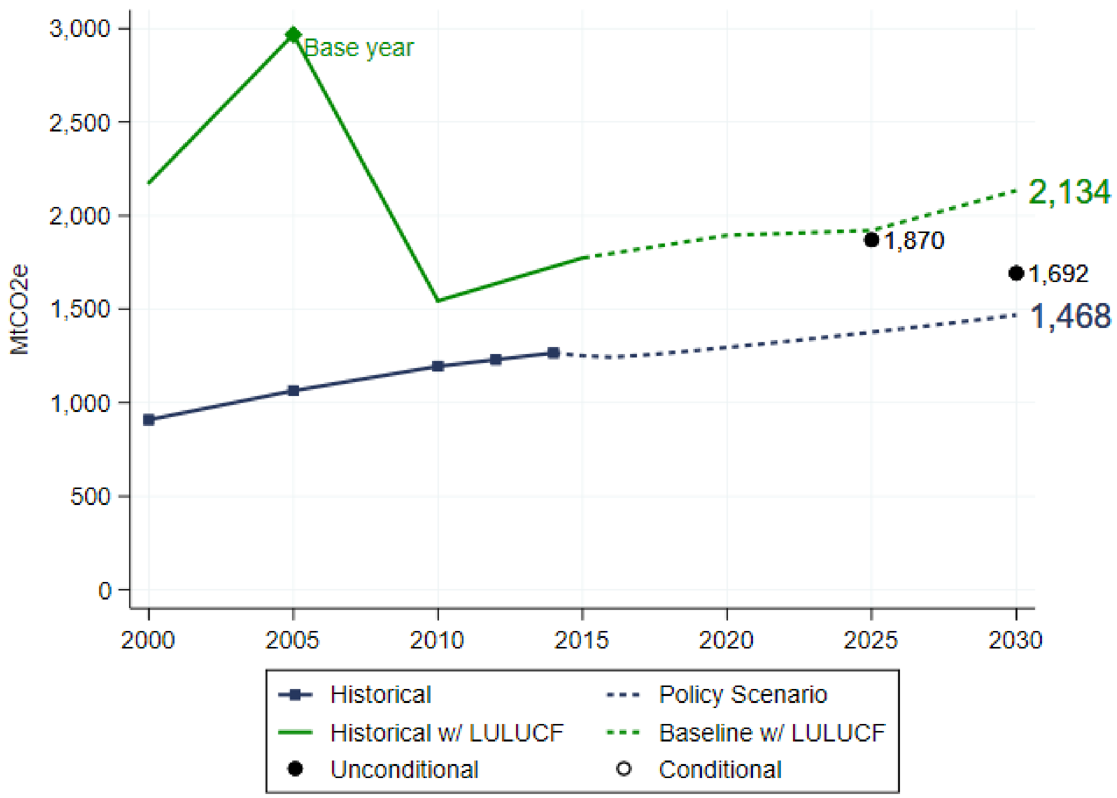

Figure 5.2.7. Brazil total emissions

Table 5.2.1. Fuel shares and generation ratios for Brazil

	Coal	Oil	Natural gas	Nuclear	Hydro	Wind/solar/ geothermal	Biofuels/ waste
2015: TPES Share	0.06	0.40	0.12	0.01	0.10	0.01	0.29
2015: Ratio - generation to TPES (GWh/ktoe)	1.55	0.25	2.26	3.84	11.63	8.47	0.56
Source: Calculations using IEA (2017a)							

Table 5.2.2. Projected growth rates for Brazil

	Average Annual Growth Rates
GDP (2016–2030)	1.62%
TPES per GDP (2016–2030)	-0.03%
Population (2016–2030)	0.61%

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

5.3 Chile

Figure 5.3.1. Map of Chile

Chile is a Latin American country forming the southwest portion of South America's Pacific coast. Chile is situated along the Andes mountain range and shares its long eastern border with Argentina, as well as its northern border with Peru and Bolivia to the northeast. Chile's capital city, Santiago, is nestled in a valley near the country's center.

According to UN (2017), Chile had a population of 17.8 million people in 2015, or 3.39% of the total population in the LAM region. Chile's population grew an average of 1.02% annually from 2000 to 2015 (compared to the LAM rate of 1.24%) and is projected to grow at an average annual rate of 0.67% from 2016 through 2030 (compared to the LAM rate of 0.83%).

In 2015 the GDP of Chile was 144 trillion Chilean pesos (2013 prices). The country experienced an average annual growth rate of 4.12% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 3.09% average annual growth rate of GDP for 2016 to 2030.

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

Chile's Policy scenario features a strong increase in generation from renewables and natural gas coupled with a phasing out of coal.

Chile's Policy scenario features a strong increase in generation from renewables and natural gas coupled with a phasing out of coal. Energy supply is informed by Chile's 2050 Energy Policy, which targets at least 60% renewables in TPES in 2030 and less than 50% carbon-intensive fuels in TPES in 2035 (Ministry of Energy, 2015).Wind/solar generating capacity expands by 16 GW from 2018 to 2030 (Patel, 2018) while generation from coal gradually decreases from a peak of about 28,000 GWh in 2018 (about 37% of total generation), to about 17,000 GWh in 2030 (16% of generation), to no generation in 2050 in response to the Chilean government's pledge not to build additional coal plants without CCS and to begin phasing out existing coal capacity. Altogether, MIT's Policy scenario for Chile yields TPES of 43,410 ktoe in 2030 with 44% oil, 21% biofuels/waste, 12% natural gas, 10% coal, 8% wind/solar/geothermal, and 6% hydro. Generation reaches 109,013 GWh in 2030 with 34% wind/solar/geothermal, 26% hydro, 16% coal, 14% natural gas, 6% biofuels/waste, and 3% oil.

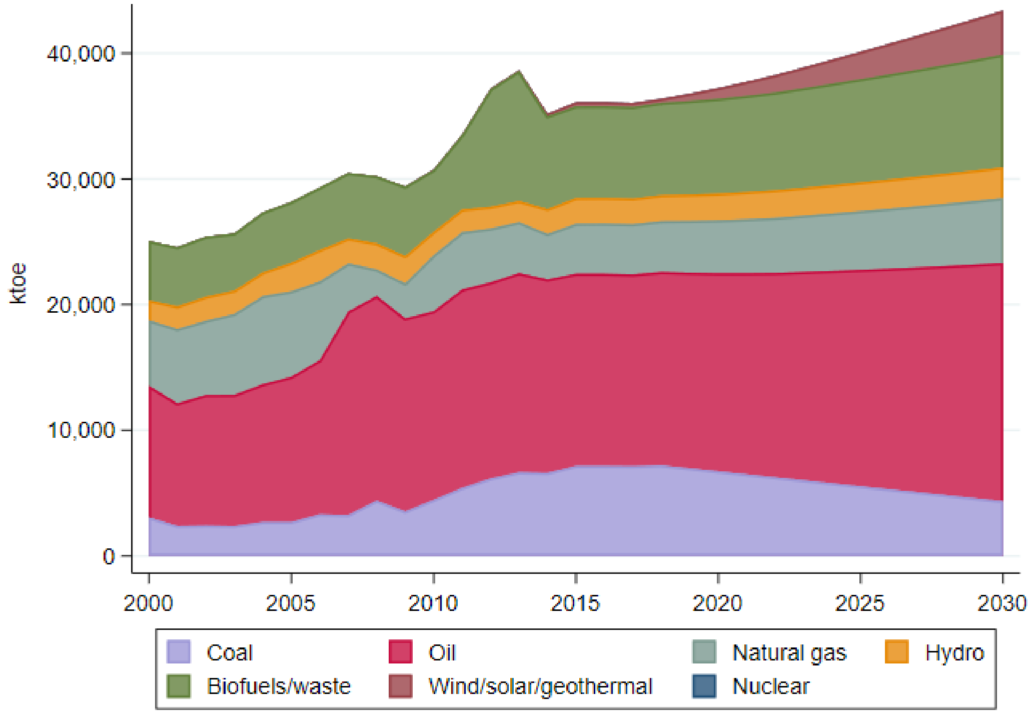

Figure 5.3.2. Chile Total Primary Energy Supply (TPES)

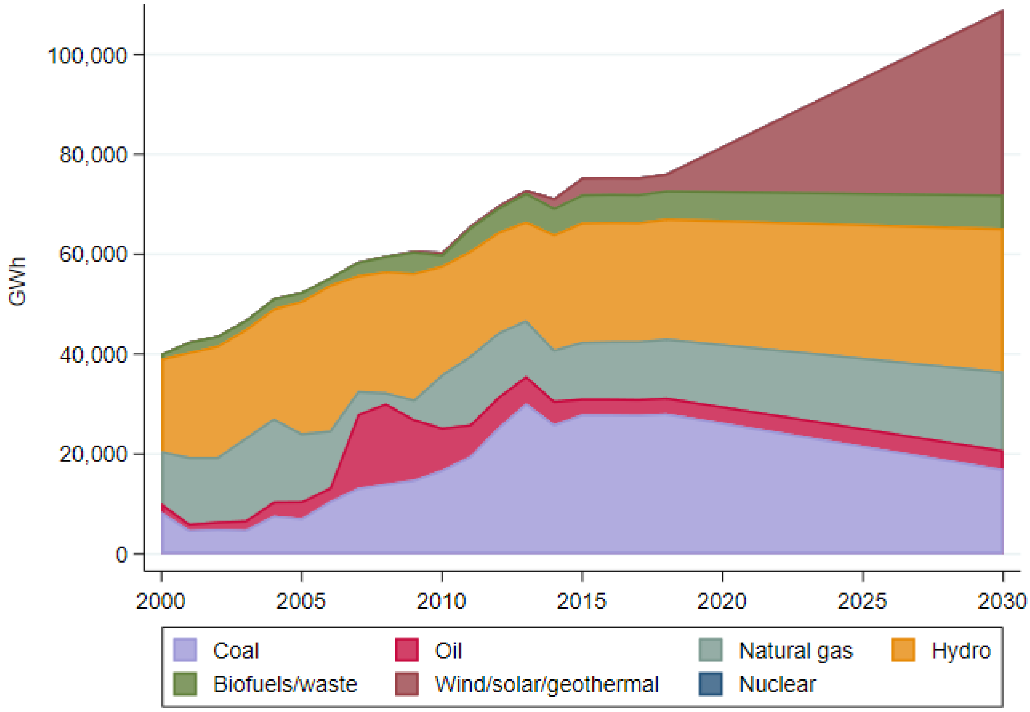

Figure 5.3.3. Chile electricity generation

In the Policy scenario, Chile is projected to emit 128 $MtCO_2e$ excluding LULUCF emissions in the year 2030, with emissions from fossil fuel combustion contributing 59% of total modeled emissions. In its NDC, Chile pledges to reduce its emissions intensity of GDP by 30% in 2030 relative to 2007, or by 35% conditional on international financial support. We model this pledge as an emissions target of 136 $MtCO_2e$ unconditionally and 126 $MtCO_2e$ conditionally, excluding LULUCF. Therefore, the emissions trajectory in the Policy scenario surpasses the unconditional NDC target by -7 $MtCO_2e$ and yields an remaining emissions gap of 2 $MtCO_2e$ from the conditional target. As a point of comparison, CAT (2018) estimates a policy emissions level of 132 $MtCO_2e$ in 2030 excluding LULUCF with an NDC unconditional target of 128 $MtCO_2e$.

Chile is also implementing mitigation measures outside of its generation mix. Beginning in 2017 a CO_2 emission tax ($5 USD/$tCO_2$) was placed on thermal power plants generating at least 50 thermal megawatts. Additionally, since 2014 Chile has charged a higher sales tax for inefficient lightweight vehicles, with the sales tax inversely proportional to performance, to incentvize more efficient vehicle production and consumption. In the forestry sector, Chile has committed to recover 100,000 hectares of forest land, and potentially reforest a further 100,000 hectares, as an official NDC pledge beyond its energy intensity goals.

Chile is also implementing mitigation measures outside of its generation mix, including a CO_2 emission tax on thermal power plants generating at least 50 thermal megawatts and a higher sales tax for inefficient lightweight vehicles.

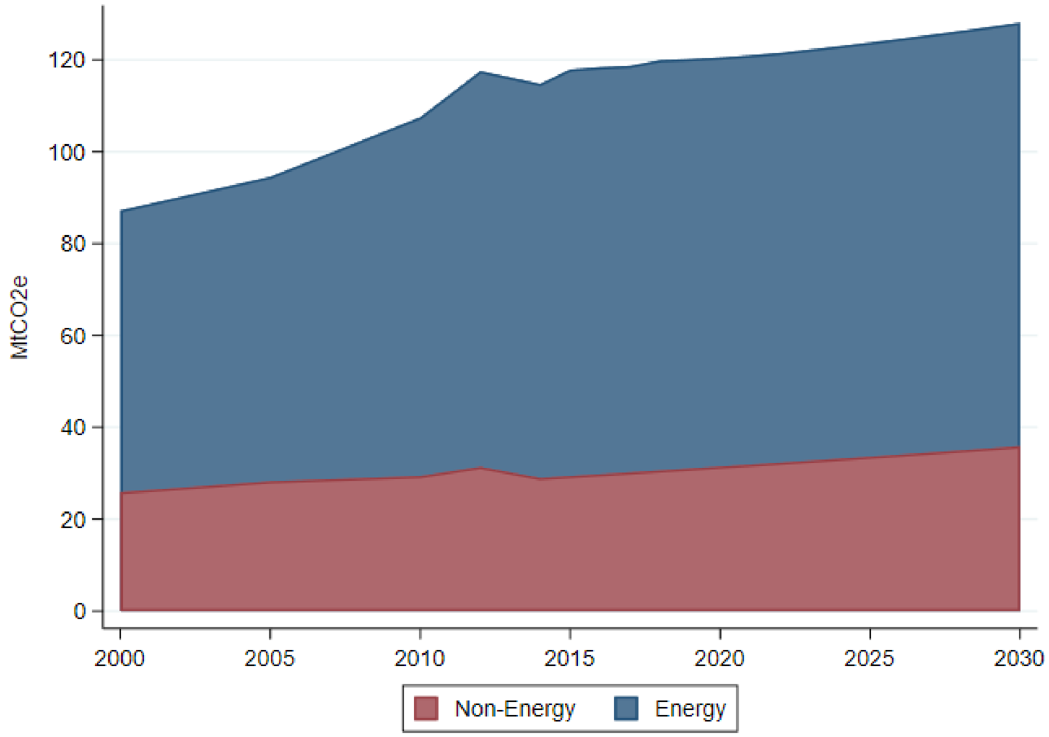

Figure 5.3.4. Chile sectoral emissions

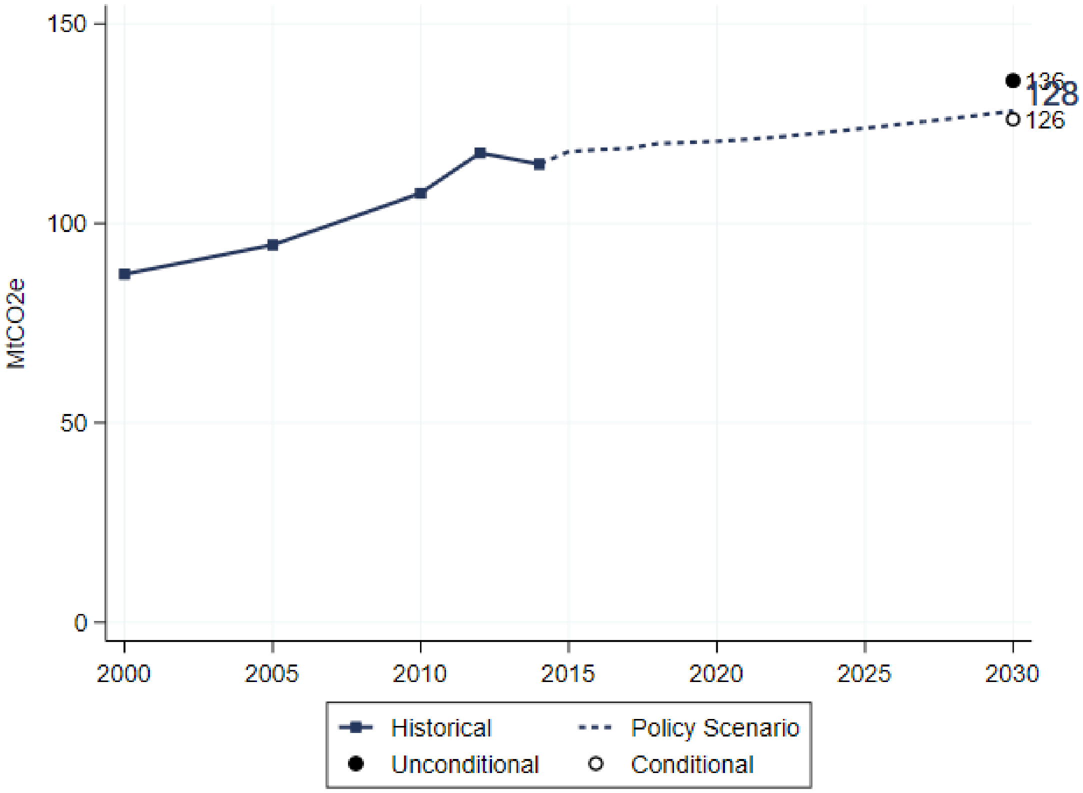

Figure 5.3.5. Chile total emissions

Table 5.3.1. Fuel shares and generation ratios for Chile

	Coal	Oil	Natural gas	Nuclear	Hydro	Wind/solar/ geothermal	Biofuels/ waste
2015: TPES Share	0.20	0.42	0.11	0	0.06	0.01	0.20
2015: Ratio - generation to TPES (GWh/ktoe)	3.91	0.21	2.85	0	11.63	10.55	0.77
Source: Calculations using IEA (2017a)							

Table 5.3.2. Projected growth rates for Chile in Policy scenario

	Average Annual Growth Rates
GDP (2016–2030)	3.09%
TPES per GDP (2016–2030)	-1.80%
Population (2016–2030)	0.67%

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

5.4 Colombia

Figure 5.4.1. Map of Colombia

Colombia is a Latin American country in the northwest corner of South America. It borders Ecuador, Peru, Brazil, Venezuela, and Panama, and has coasts on both the Pacific Ocean and the Caribbean Sea. Colombia's capital city, Bogotá, is situated at a high altitude in the central region of the country

According to UN (2017), Colombia had a population of 48.2 million people in 2015, or 9.21% of the total population in the LAM region. Colombia's population grew an average of 1.19 % annually from 2000 to 2015 (compared to the LAM rate of 1.24%) and is projected to grow at an average annual rate of 0.65% from 2016 through 2030 (compared to the LAM rate of 0.83%).

In 2015 the GDP of Colombia was 531 trillion Colombian pesos (2005 prices). The country experienced an average annual growth rate of 4.24% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 3.45% average annual growth rate of GDP for 2016 to 2030.

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

In its Third National Communication to the UNFCCC, Colombia defines its sectoral climate strategies and provides estimates of the mitigation potential within each government ministry (discussed in more depth below). To estimate Policy scenario emissions, we apply select mitigation measures to an emissions scenario based on BAU generation plans designed by Colombia's national mining and energy planning unit (UPME, 2017). This reference case scenario yields 23.5 GW of generation capacity in 2030 with hydro, gas, and coal-fired plants respectively contributing 57%, 16% and 11% of total capacity. We estimate electricity output from these capacities using capacity factors summarized in Table 5.4.1 and based on the historical capacity and generation data presented in Colombia's First Biennial Update to the UNFCCC (IDEAM *et al.* 2015). Altogether, we estimate total generation in 2030 of 108,546 GWh consisting of 58% hydro, 24% natural gas, 13% coal, 4% wind/solar/geothermal, and 1% biofuels/waste. TPES in 2030 is 44,138 ktoe with a fuel make-up of 35% oil, 27% natural gas, 16% coal, 12% hydro, 8% biofuels/waste, and 1% other renewables. Coal maintains a significant role in the energy mix as Colombia has the largest coal reserves in Latin America.

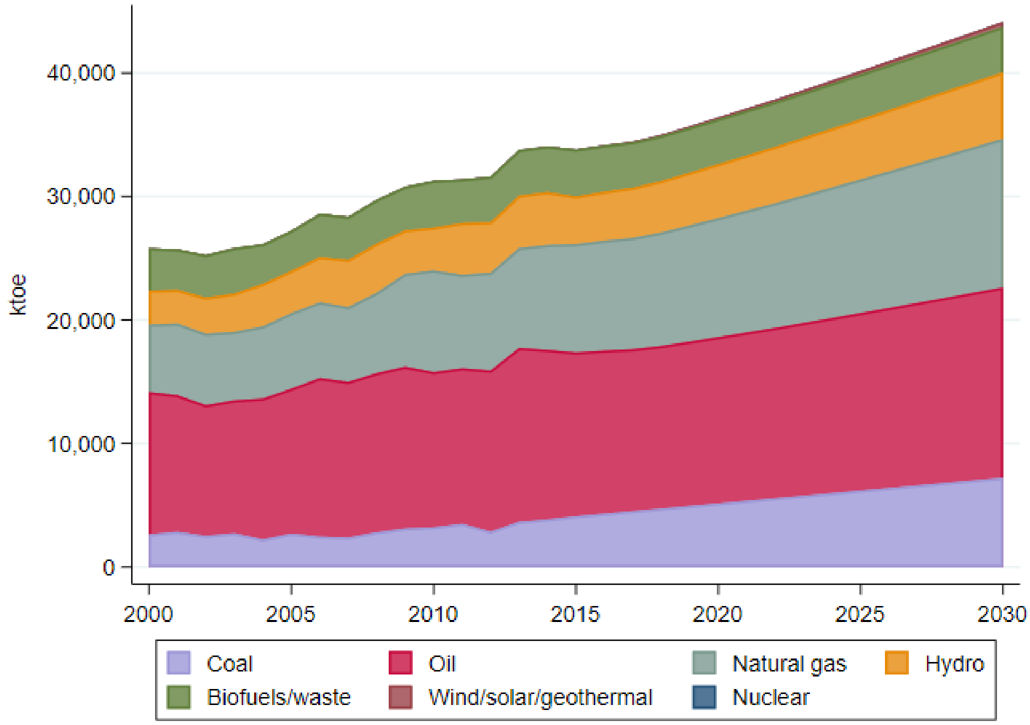

Figure 5.4.2. Colombia Total Primary Energy Supply (TPES)

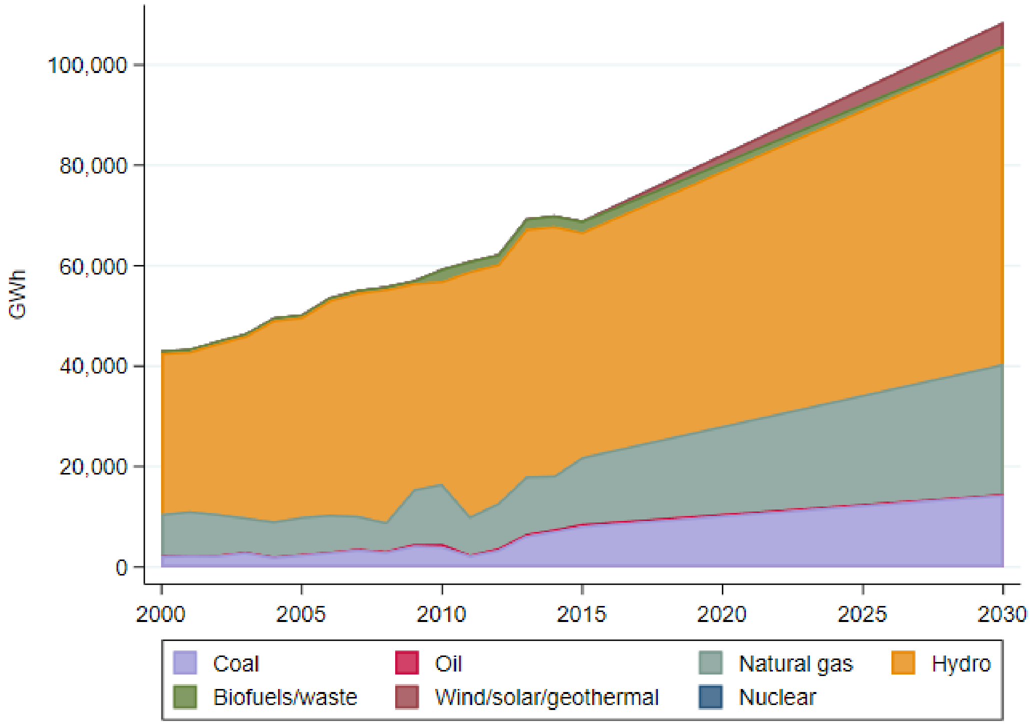

Figure 5.4.3. Colombia electricity generation

In the Policy scenario, Colombia is projected to emit 184 $MtCO_2e$ excluding LULUCF emissions in the year 2030, with fossil fuel combustion contributing 52% of total modeled emissions. To form this estimate, we design an emissions trajectory in line with the above BAU generation scenario and then apply mitigation measures included in Colombia's Third National Communication to the UNFCCC (IDEAM *et al.* 2017). Specifically, we include reductions in 2030 of

- **11.2 $MtCO_2e$ from the Ministry of Mining and Energy**, with contributions of 1.21 $MtCO_2e$ from energy efficiency, 3.24 $MtCO_2e$ from fugitive emissions, 4.74 $MtCO_2e$ from generation, and 2.01 from demand management,
- **6.987 $MtCO_2e$ from the Ministry of Environment and Sustainable Development** (e.g., through distribution of energy-efficient cook stoves and improved energy efficiency in buildings)
- **4.977 $MtCO_2e$ from the Ministry of Transportation** (e.g., through improved public transportation, adoption of electric vehicles, and optimized cargo transport and logistics).
- **3.079 $MtCO_2e$ from the Ministry of Commerce, Industry, and Tourism** (e.g., through energy efficiency incentive programs and the use of biomass residues for industrial processes)
- **0.930 $MtCO_2e$ from the Ministry of Life, City, and Territory** (e.g., through recycling and composting programs, sustainable construction practices, and public financing of renewable energy programs)
- **0.067 $MtCO_2e$** from commercial and public institutions (e.g., hospitals, public universities, hotels, etc.)

While a further 16.184 $MtCO_2e$ of reductions are identified by the Ministry of Agriculture and Rural Development, we conservatively do not consider include these reductions so as to exclude measures targeting LULUCF.

In its NDC, Colombia pledges to reduce its emissions in 2030 by 20% relative to the BAU, or by 30% conditional on international financial support. As Colombia includes in its Third National Communication a projection of 83 $MtCO_2e$ of emissions from deforestation under its 2030 BAU, and states an intention to mitigate 32.4 $MtCO_2e$ of these emissions (IDEAM *et al.* 2017), we adjust Colombia's modeled pledges to a 14% unconditional and 27% conditional reduction from BAU to exclude deforestation measures from the official targets. Therefore, the trajectory in the Policy scenario yields emissions targets of 169 $MtCO_2e$ unconditionally and 144 $MtCO_2e$ conditionally.

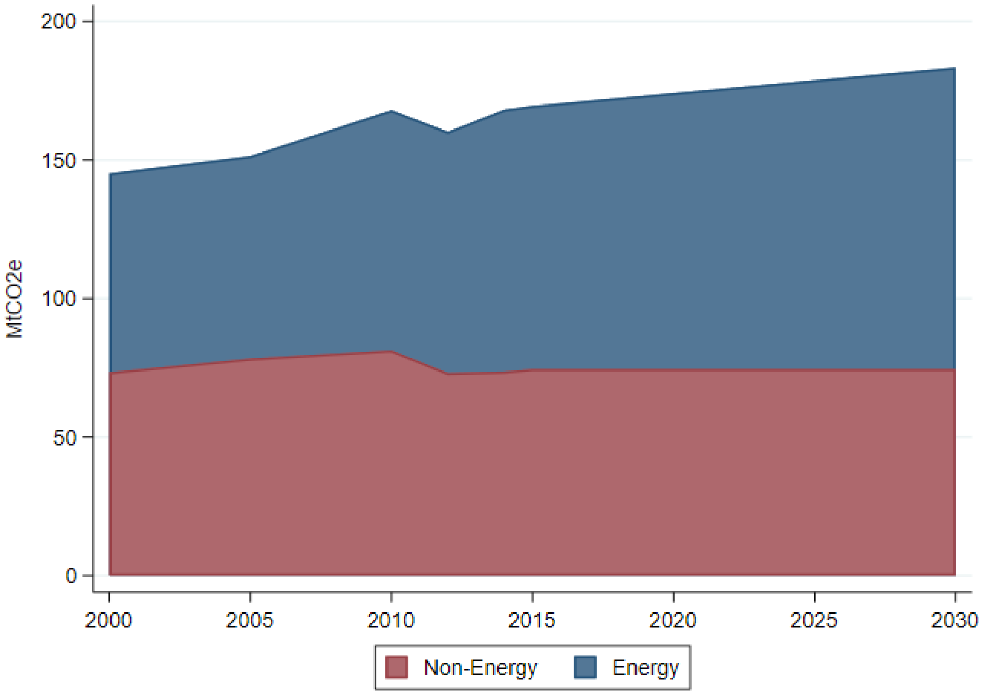

Figure 5.4.4. Colombia sectoral emissions

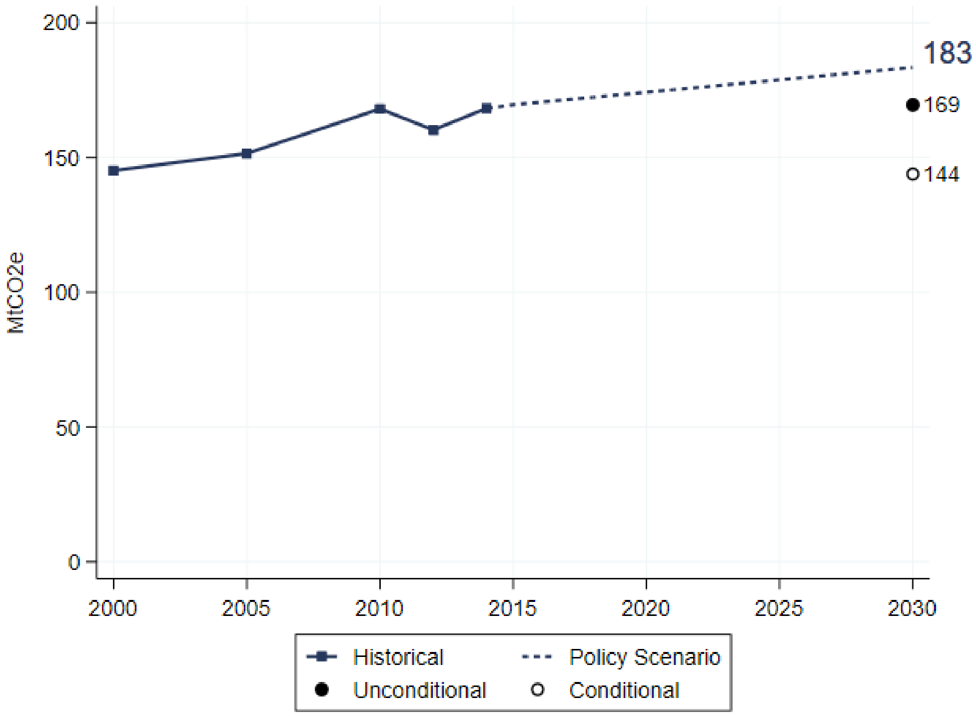

Figure 5.4.5. Colombia total emissions

Table 5.4.1. Capacity factors, fuel shares, and generation ratios for Colombia

	Coal	Oil	Natural gas	Nuclear	Hydro	Wind/solar/ geothermal	Biofuels/ waste
Generation capacity factors	0.64	0.21	0.57	0.80	0.53	0.30	0.21
2015: TPES Share	0.12	0.39	0.26	0	0.11	0.00	0.11
2015: Ratio - generation to TPES (GWh/ktoe)	1.99	0.03	1.52	0	11.63	11.63	0.58

Source: Calculations using IEA (2017a)

Table 5.4.2. Projected growth rates for Colombia in Policy scenario

	Average Annual Growth Rates
GDP (2016–2030)	3.45%
TPES per GDP (2016–2030)	-1.60%
Population (2016–2030)	0.67%

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

5.5 Ecuador

Figure 5.5.1. Map of Ecuador

Ecuador is a country in northwestern South America centered on the Earth's equator. It includes the archipelagic Galapagos Islands in the Pacific Ocean, and its mainland is bordered by Colombia, Peru, and the Pacific Ocean. Its capital city, Quito, is the second-highest altitude official capital city in the world. Notably, Ecuador was the first country to legally recognize Nature as a right-holding entity.

According to UN (2017), Ecuador had a population of 16.1 million people in 2015, or 3.08% of the total population in the LAM region. Ecuador's population grew an average of 1.65% annually from 2000 to 2015 (compared to the LAM rate of 1.24%) and is projected to grow at an average annual rate of 1.29% from 2016 through 2030 (compared to the LAM rate of 0.83%).

In 2015 the GDP of Ecuador was 70.4 billion U.S. dollars (2007 prices). The country experienced an average annual growth rate of 4.24% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 1.69% average annual growth rate of GDP for 2016 to 2030.

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

For the Policy scenario, we consider both Ecuador's Master Electricity Plan (PME) 2016-2025 and its National Energy Efficiency Plan (PLANEE) 2016-2035 to model energy use out to 2030 (MEER, 2017a, 2017b). While oil produced about 35% of Ecuador's electricity in 2015, the role of oil in generation rapidly decreases as Ecuador's largest hydropower project to date, Coca

Coda Sinclair, comes online in 2016 and adds 1,500 MW of hydropower capacity (MEER, 2018; Valencia, 2017). Additionally, Ecuador cites small-scale expansion in generation from biofuels and other unconventional renewables prior to 2030. In terms of energy efficiency, Ecuador is targeting improvements in all sectors, and aims for cumulative savings of 83.7 million barrels of oil equivalent (mboe) for 2007 to 2035 in the energy sector alone. We incorporate this energy efficiency goal into the Policy scenario as an annual reduction of 963 ktoe in 2030 relative to the Baseline scenario. Combining these generation and energy efficiency plans, we project TPES of 19,312 ktoe in 2030 with a fuel breakdown of 76% oil, 16% hydro, 6% biofuels, and 3% natural gas. Electricity generation reaches 48,526 GWh in 2030 and consists of 72% hydro, 18% oil, 7% natural gas, and 2% non-hydro renewables.

In the Policy scenario, Ecuador is projected to emit 80 $MtCO_2e$ excluding LULUCF emissions in 2025, the year targeted by Ecuador's official NDC pledges, which we extend to 85 $MtCO_2e$ in 2030 with fossil fuel combustion contributing 64% of total modeled emissions. In its NDC, Ecuador pledges to reduce its energy sector emissions in 2025 by 20.4% to 25% relative to its BAU, or by 37.5% to 45.8% conditional on international financial support. Adopting the low ends of these target ranges, we estimate that the 2025 emission targets would be consistent with 2030 targets of 69 $MtCO_2e$ unconditionally and 54 $MtCO_2e$ conditionally. Therefore, we calculate that Policy scenario trajectory yields an emissions gap in 2030 of 16 $MtCO_2e$ (19%) from the unconditional target and 31 $MtCO_2e$ (36%) from the conditional target, considering mitigation measures in the energy sector alone.

Outside of the energy industries, Ecuador is implementing economy-wide efficiency measures with a targeted cumulative economy-wide savings of 543 mboe (about 11,700 ktoe and 65 $MtCO_2e$) for 2007 to 2035. The goal will be achieved in part through improved energy efficiency standards and construction practices in the residential, commercial, and public sectors, and through cogeneration and the replacement of inefficient equipment in the industrial sector (MEER, 2017b). Additionally, Ecuador has adopted reforestation goals with annually increasing ambition, targeting hundreds of thousands of hectares for reforestation each year through 2025.

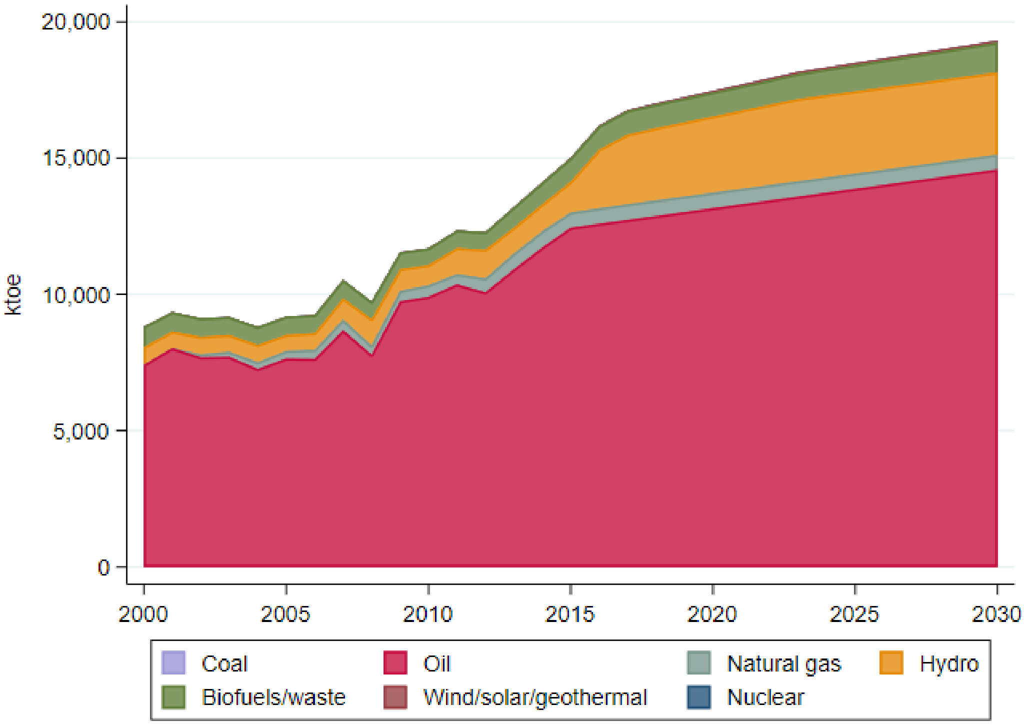

Figure 5.5.2. Ecuador Total Primary Energy Supply (TPES)

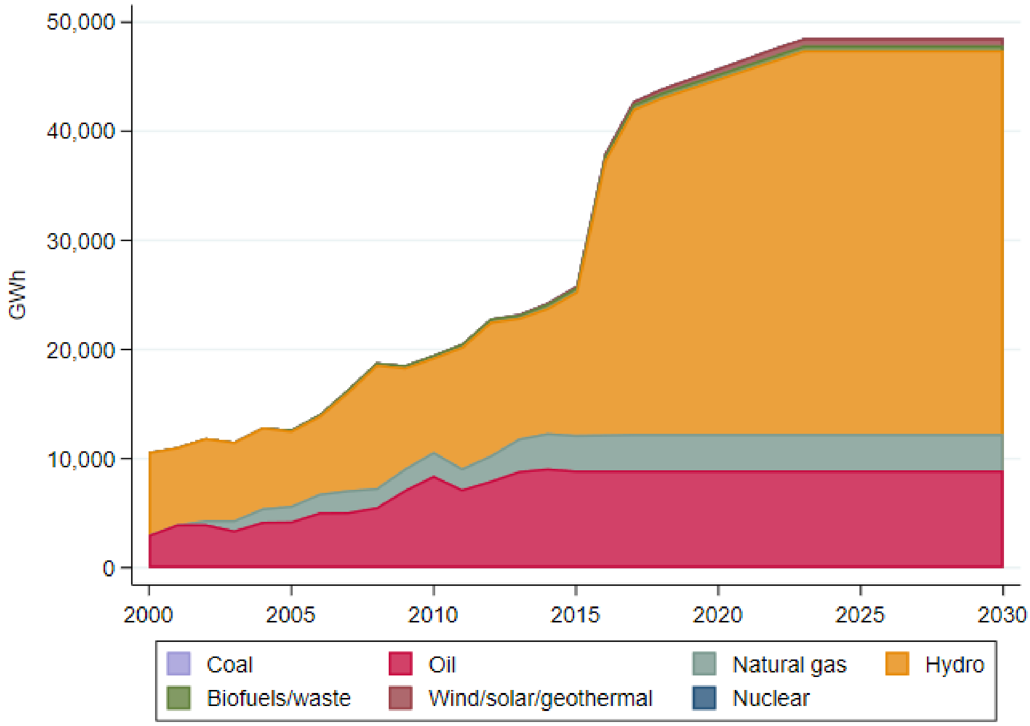

Figure 5.5.3. Ecuador electricity generation

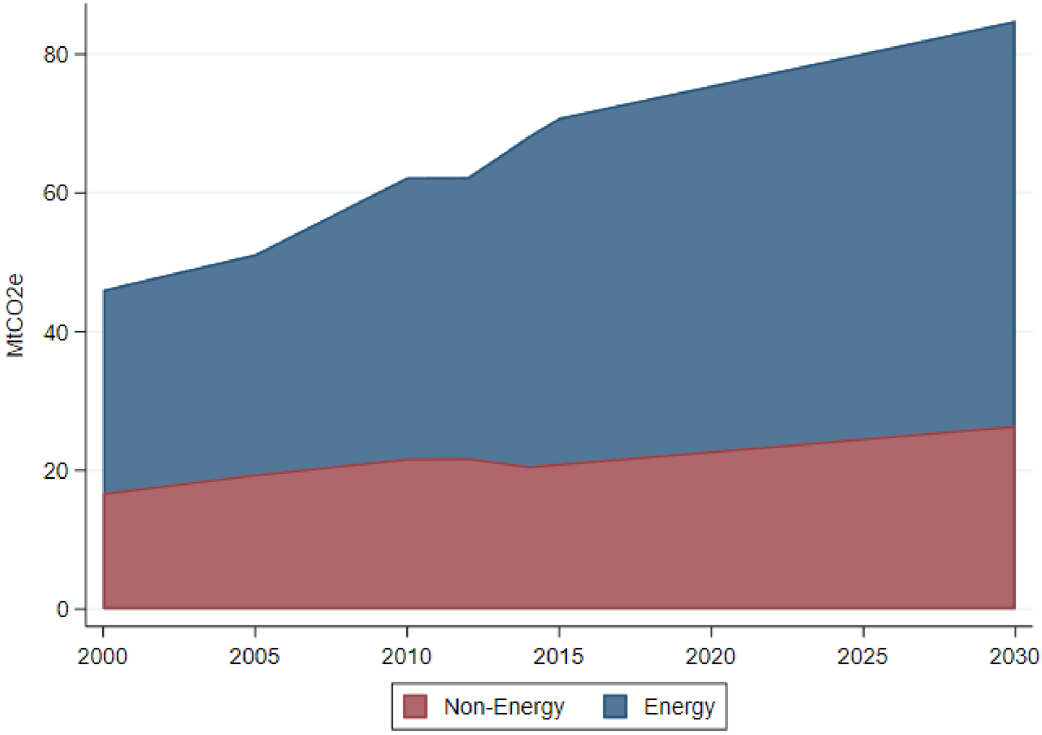

Figure 5.5.4. Ecuador sectoral emissions

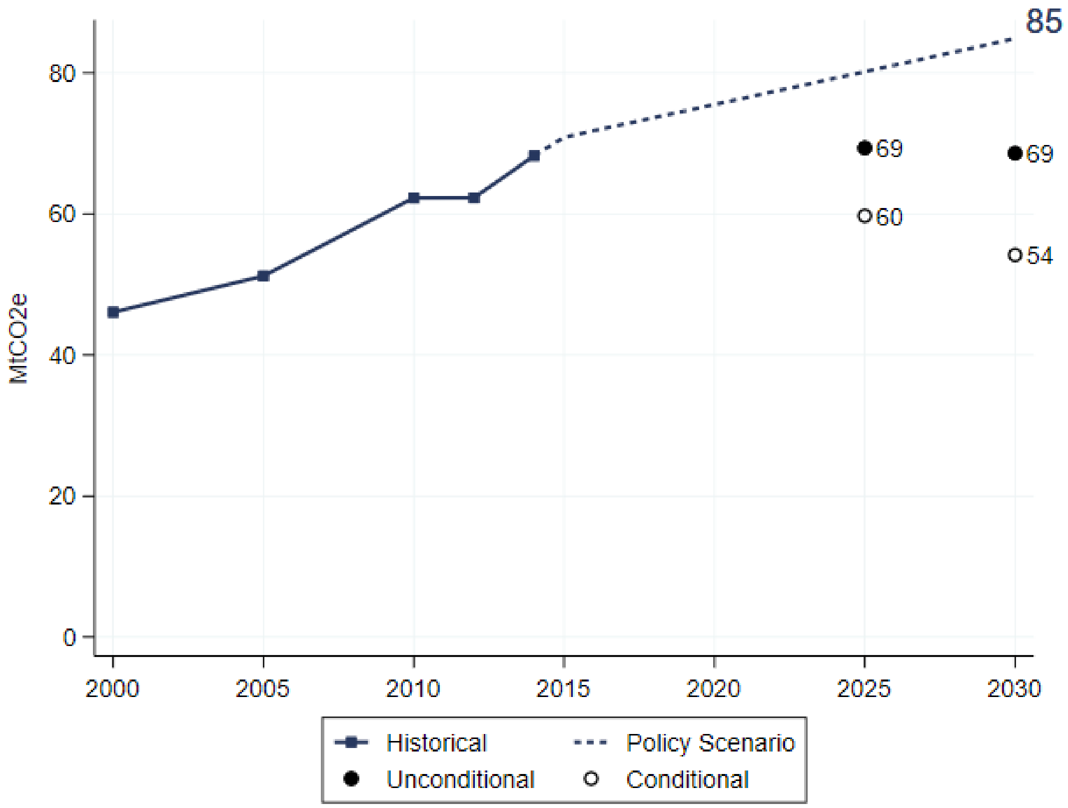

Figure 5.5.5. Ecuador total emissions

Table 5.5.1. Fuel shares and generation ratios for Ecuador

	Coal	Oil	Natural gas	Nuclear	Hydro	Wind/solar/ geothermal	Biofuels/ waste
2015: TPES Share	0	0.83	0.04	0	0.08	0.00	0.06
2015: Ratio - generation to TPES (GWh/ktoe)	0	0.72	5.85	0	11.63	9.61	0.47
Source: Calculations using IEA (2017a)							

Table 5.5.2. Projected growth rates for Ecuador in Policy scenario

	Average Annual Growth Rates
GDP (2016–2030)	3.45%
TPES per GDP (2016–2030)	-1.60%
Population (2016–2030)	0.67%

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

5.6 Mexico

Figure 5.6.1. Map of Mexico

Mexico is a country in the southern portion of North America. It borders the United States to the north and the Central American countries Guatemala and Belize to the south. Mexico also has coasts on the Pacific Ocean to the west and the Gulf of Mexico and the Caribbean Sea to the east. Mexico City, the capital of Mexico and North America's most populous city, is situated in a high-altitude valley in the country's central region.

According to UN (2017), Mexico had a population of 126 million people in 2015, or 24.03% of the total population in the LAM region. Mexico's population grew an average of 1.43% annually from 2000 to 2015 (compared to the LAM rate of 1.24%) and is projected to grow at an average annual rate 1.06% from 2016 through 2030 (compared to the LAM rate of 0.83%).

In 2015 the GDP of Mexico was 14.1 trillion Mexican pesos (2008 prices). The country experienced an average annual growth rate of 2.17% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 2.31% average annual growth rate of GDP for 2016 to 2030.

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

Under the Policy scenario, TPES in Mexico reaches 209,650 ktoe in 2030 with a fuel makeup of 39% oil, 38% natural gas, 9% wind/solar/geothermal, 6% biofuels/waste, 5% nuclear, 2% hydro, and 1% coal. Total generation in 2030 is 443,531 GWh with 60% natural gas, 16% wind/solar/geothermal, 11% hydro, 9% nuclear, 2% biofuels/waste, and 1% coal. These estimates are based on the technology-specific generation plan published by Mexico's Secretariat of Energy (SENER) in its Electricity Sector Outlook 2016-2030 (SENER, 2017) and reflect Mexico's commitment to decreasing the use of coal in favor of cleaner technologies including renewables, cogeneration with natural gas, and thermal generation with carbon capture. In addition, Mexico intends to improve energy efficiency in its transportation, oil, and commercial/residential building sectors with a goal of reducing emissions in these sectors by 10% to 20% in 2030 relative to the BAU.

In comparison to MIT's estimates of a 2030 energy supply of 210 Mtoe and generation of 444 TWh, the IEA Mexico Energy Outlook projects an energy demand and generation level of 206 Mtoe and 422 TWh for Mexico in 2030 in the New Policies Scenario (IEA, 2016). Figures 5.6.4 and 5.6.5 compare MIT and IEA (2016)'s energy supply and generation projections by fuel under climate policy. While results are similar, MIT is more optimistic about the growth of natural gas and the decline of coal and oil by 2030.

In the Policy scenario, Mexico is projected to emit 789 $MtCO_2e$ excluding LULUCF emissions in the year 2030, with emissions from fossil fuel combustion contributing 54% of total modeled emissions. In its NDC, Mexico pledges to reduce its GHG emissions by 22% in 2030 relative to its BAU, or by 36% conditional on international financial support. However, beyond its NDC, Mexico has published a sectoral breakdown of its BAU and targeted emissions for 2030 consistent with the country's unconditional pledge (Government of Mexico, 2015). Using the country-specified planned reductions in the LULUCF sector, we model Mexico's pledges as an 18% unconditional and 32% conditional reduction in GHG emissions relative to the 2030 BAU excluding LULUCF. This reframed pledge results in an emissions target of 757 $MtCO_2e$ unconditionally and 628 $MtCO_2e$ conditionally. Therefore, the Policy scenario trajectory yields a remaining emissions gap from the 2030 GHG target of 32 $MtCO_2e$ unconditionally (4% of Policy emissions) and 161$MtCO_2e$ conditionally (20% of Policy emissions).

Mexico's sectoral breakdown of its BAU and targeted emissions reveal that LULUCF is a relatively minor component of the current emissions profile but is viewed as an important part of the national climate strategy for the carbon absorption potential.[3] Additionally, while Mexico's generation plans substantially close the gap between the Policy trajectory and target emissions, remaining mitigation efforts will fall to other areas of energy consumption, most notably oil use in the transportation sector.

> *While Mexico's generation plans substantially close the gap between the Policy trajectory and target emissions, remaining mitigation efforts will fall to other areas of energy consumption, most notably oil use in the transportation sector.*

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[3] For the LULUCF sector in 2030, Mexico projects BAU emissions of 32 $MtCO_2e$ (3% of economy-wide emissions) with a targeted reduction of 46 $MtCO_2e$ (22% of economy-wide planned reductions) for net emissions of -14 $MtCO_2e$.

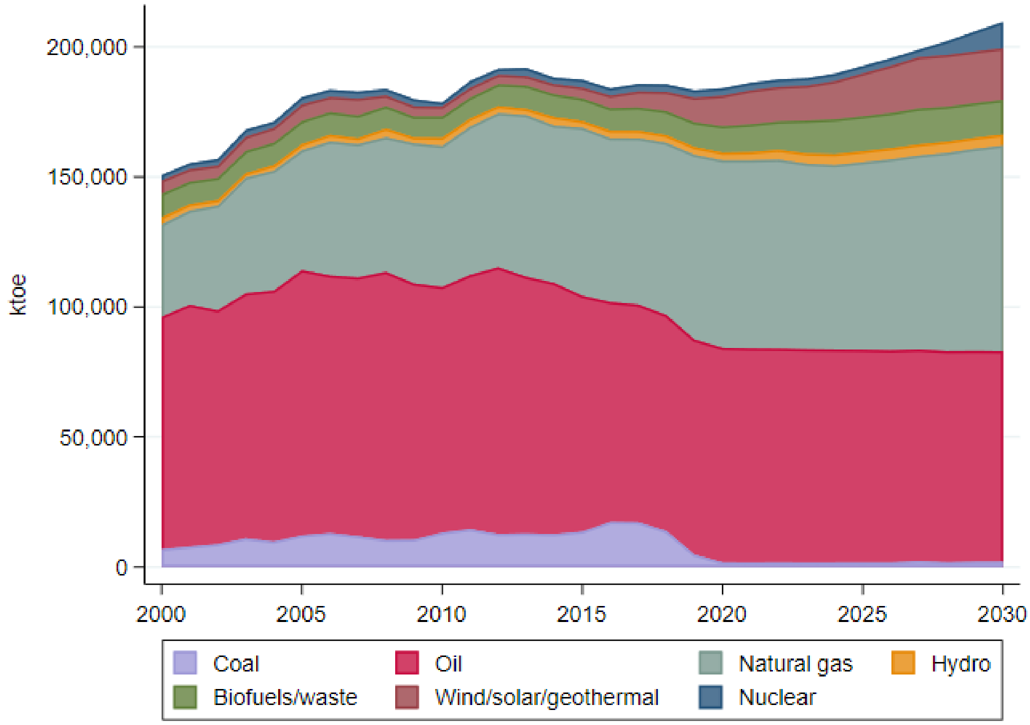

Figure 5.6.2. Mexico Total Primary Energy Supply (TPES)

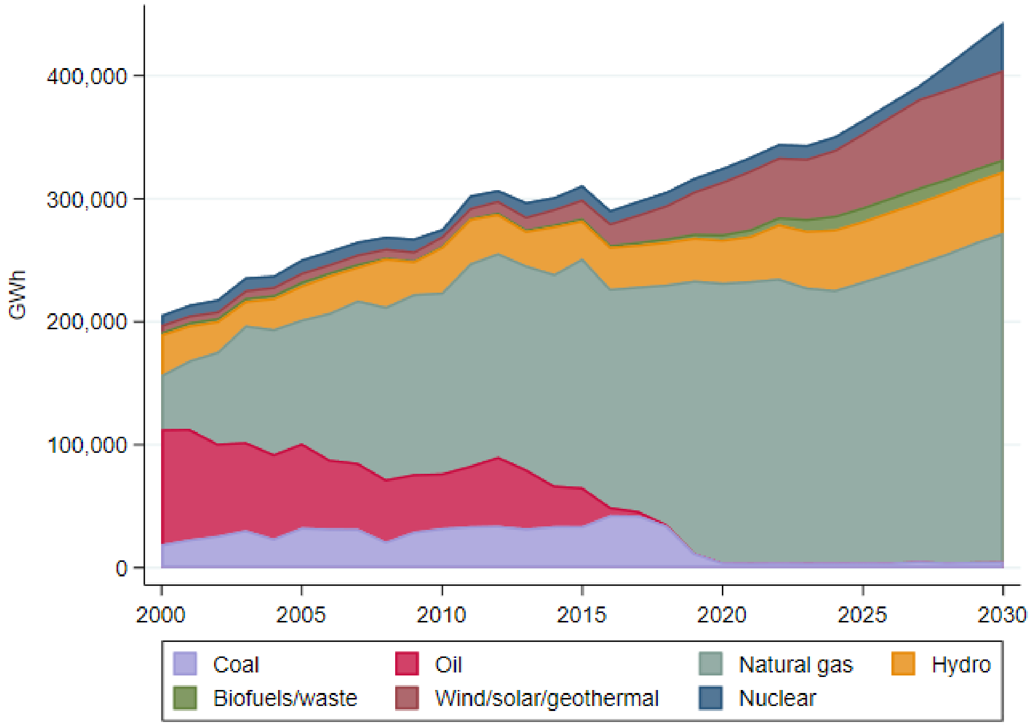

Figure 5.6.3. Mexico electricity generation

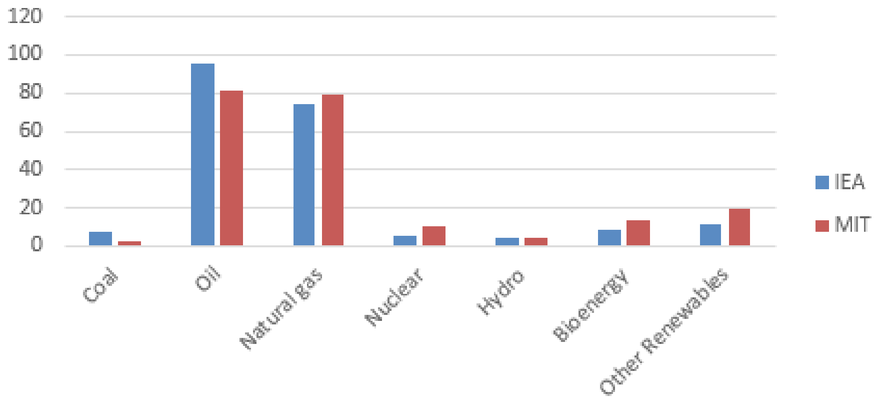

Figure 5.6.4. IEA (2017b) and MIT estimates of energy supply in Mexico in 2030

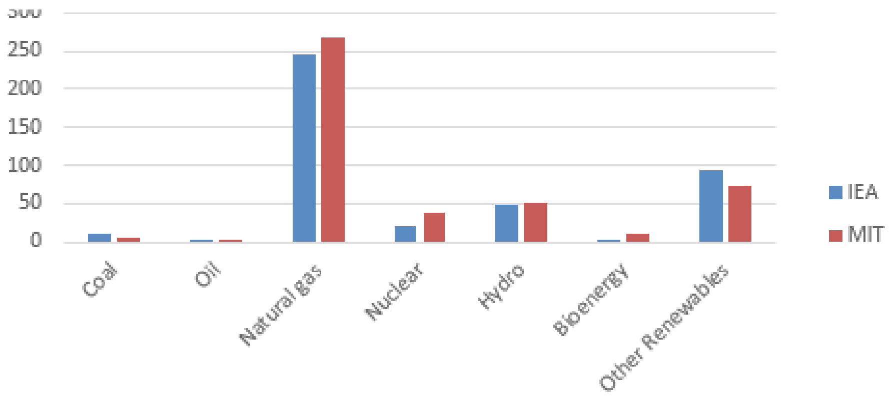

Figure 5.6.5. IEA (2017b) and MIT estimates of generation in Mexico in 2030

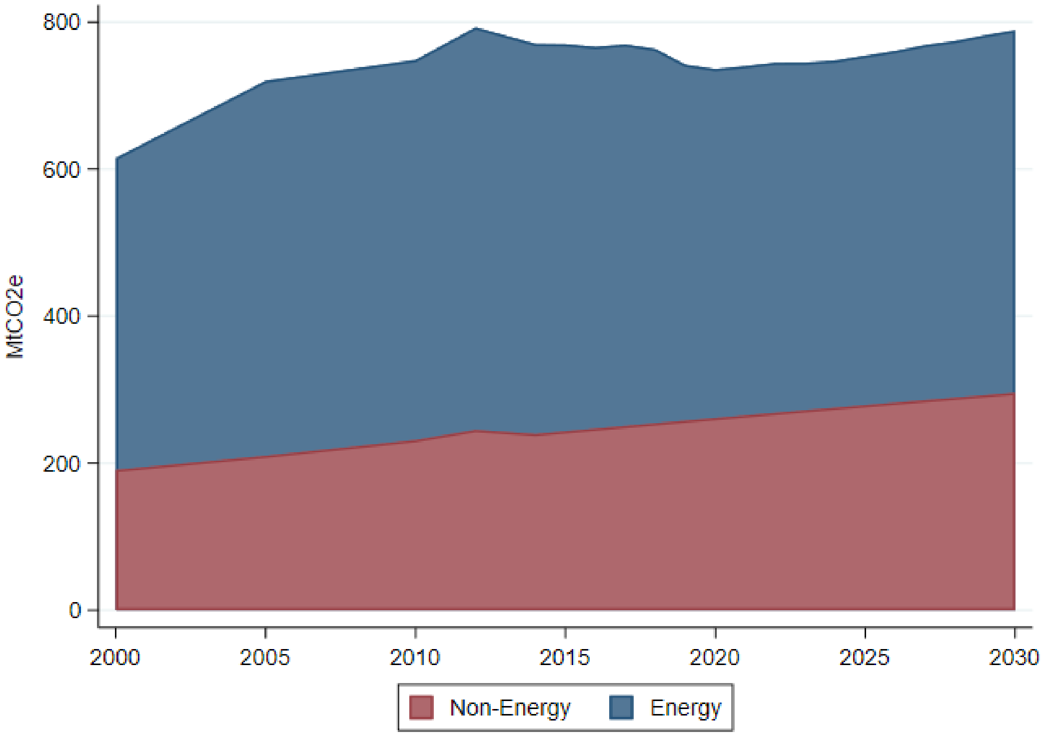

Figure 5.6.6. Mexico sectoral emissions

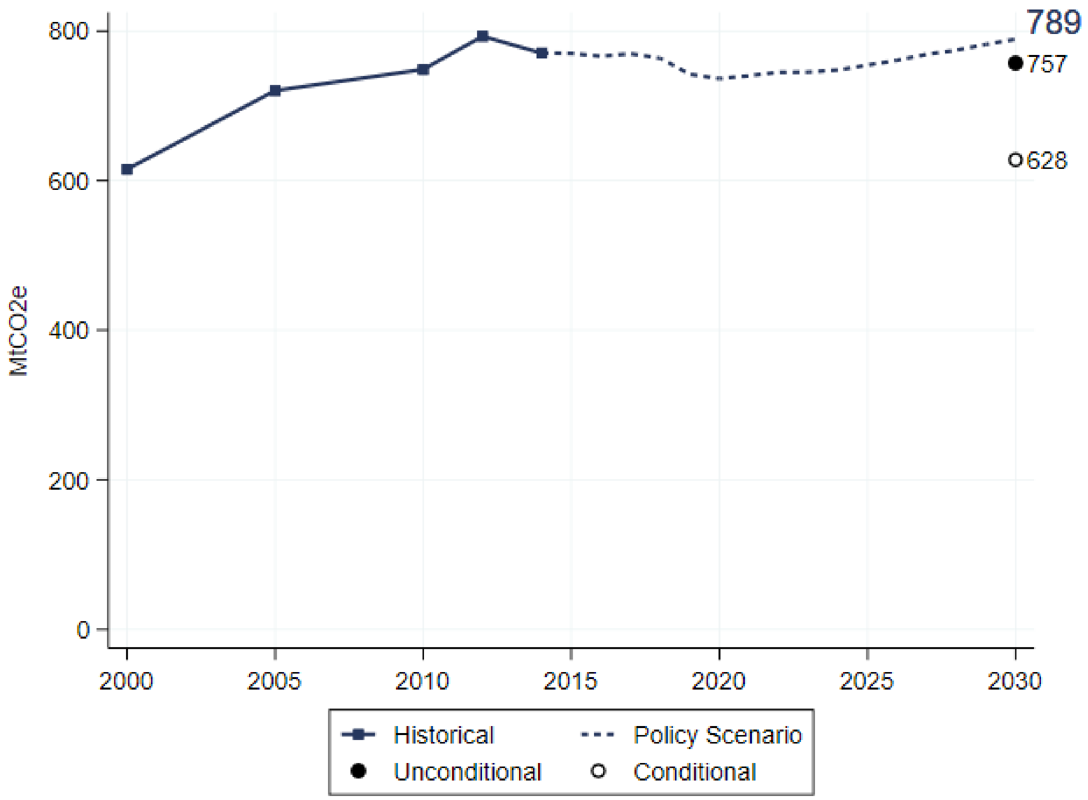

Figure 5.6.7. Mexico total emissions

Table 5.6.1. Fuel shares and generation ratios for Mexico

	Coal	Oil	Natural gas	Nuclear	Hydro	Wind/solar/ geothermal	Biofuels/ waste
2015: TPES Share	0.07	0.48	0.34	0.02	0.01	0.02	0.05
2015: Ratio - generation to TPES (GWh/ktoe)	2.48	0.35	2.88	3.84	11.63	3.65	0.21
Source: Calculations using IEA (2017a)							

Table 5.6.2. Projected growth rates for Mexico in Policy scenario

	Average Annual Growth Rates
GDP (2016–2030)	2.31%
TPES per GDP (2016–2030)	-1.52%
Population (2016–2030)	1.06%

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

5.7 Panama

Figure 5.7.1. Map of Panama

Panama is a small Latin American country linking Central and South America. It is bordered by Costa Rica to the northwest and Colombia to the southeast. The country's capital city, Panama City, is situated on the southern coast along Panama Bay and the Pacific Ocean. The Panama Canal, a man-made waterway in the country's center, connects the Pacific Ocean with the Atlantic Ocean to the north, and greatly facilitates maritime trade by reducing the energy and time requirements of international shipping.

According to UN (2017), Panama had a population of 4.0 million people in 2015, or 0.76% of the total population in the LAM region. Panama's population grew an average of 1.82% annually from 2000 to 2015 (compared to the LAM rate of 1.24%) and is projected to grow at an average annual rate of 1.39% from 2016 through 2030 (compared to the LAM rate of 0.83%).

In 2015 the GDP of Panama was 35.7 billion U.S. dollars (2007 prices). The country experienced an average annual growth rate of 6.47% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 5.82% average annual growth rate of GDP for 2016 to 2030.

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

We formulate Panama's policy scenario to parallel the capacity expansion plans specified in its National Energy Plan 2015-2050, which was designed to accommodate an expected 600% increase in electricity demand by 2050 (SNE, 2016). While hydropower represented 61% of

Panama's electricity generation in 2015, the country intends to increase generation from wind, solar, and biomass with a goal of reaching 30% of capacity sourced from non-hydro renewables in 2050 (SNE, 2016). As part of this trajectory, we estimate electricity generation in Panama will reach 20,066 GWh in 2030 with a fuel makeup of 53% hydro, 26% wind/solar, 13% oil, 5% natural gas, and 3% coal. Beyond the generation sector, the estimated TPES for Panama in 2030 is 5,081 ktoe—a 12% decrease from Panama's 2030 Baseline energy supply—with 58% oil, 18% hydro, 9% wind/solar, 7% natural gas, 5% biofuels/waste, and 3% coal. While oil remains the dominant fuel in Panama's total energy supply, its level decreases by 7% from 2015 to 2030 while natural gas enters the energy matrix, growing from almost no contribution in 2015 to 356 ktoe in 2030. However, going forward, coal will play an increasing role in meeting the country's growing electricity demands in the post-2030 years (SNE, 2016).

In the Policy scenario, Panama is projected to emit 19.0 $MtCO_2e$ excluding LULUCF emissions in the year 2030, with fossil fuel combustion contributing 49% of total modeled emissions. In its NDC, Panama pledges to expand the generation capacity of non-hydro renewables by 30% in 2050 relative to 2014, a goal that is indicative of meeting 30% of its total generation capacity in 2050 (and 15% in 2030) with non-hydro renewables. We model this goal as an increase in the share of renewables in total generation output to 15% in 2030 conditional on international financial support, yielding an emissions target of 22.8 $MtCO_2e$. Therefore, the Policy scenario trajectory overachieves the NDC target in 2030 by 20% of the Policy scenario emissions. While Panama also specifies official LULUCF targets, including a 10% increase in carbon absorption capacity in 2050 relative to the BAU (and an 80% increase conditional on international support), the electricity generation sector is Panama's main target to decreasing nationwide emissions.

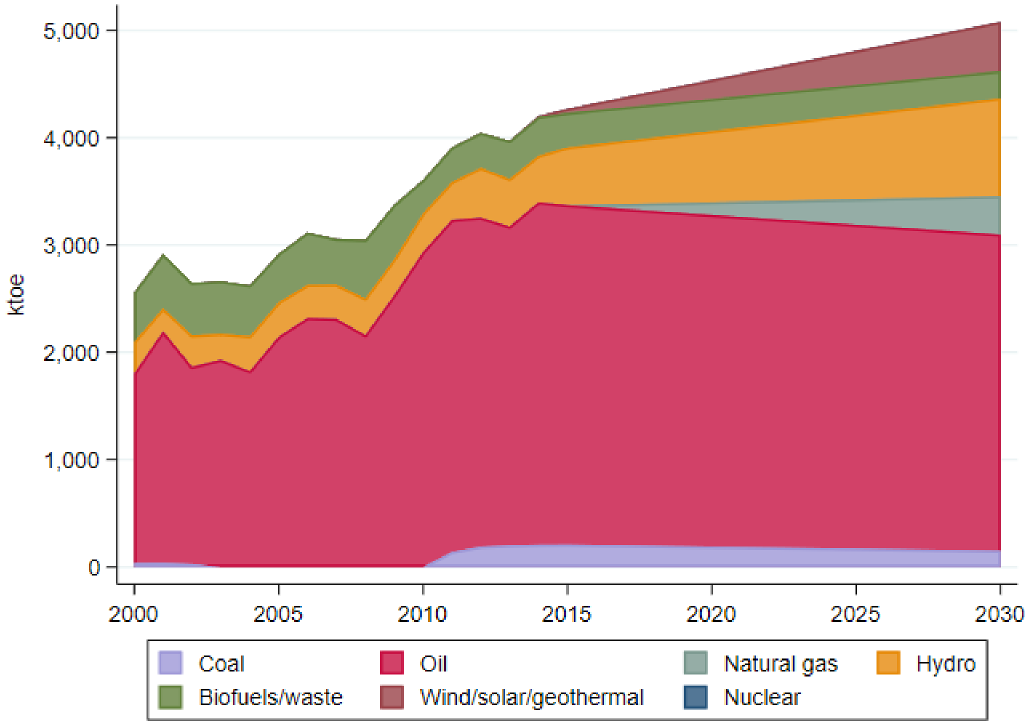

Figure 5.7.2. Panama Total Primary Energy Supply (TPES)

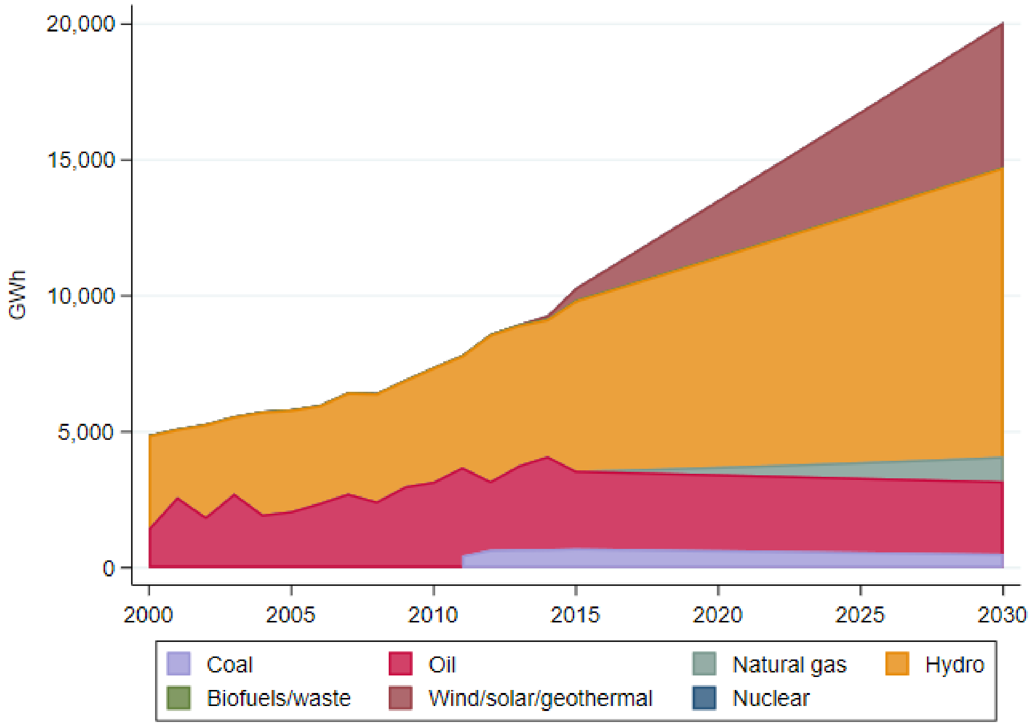

Figure 5.7.3. Panama electricity generation

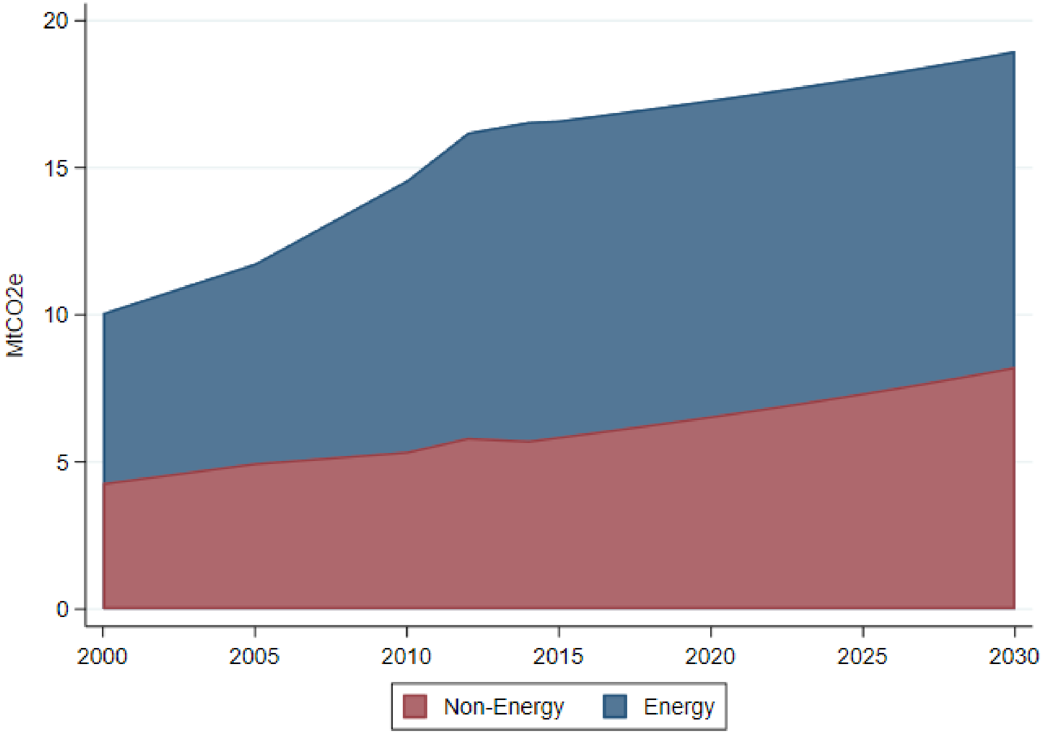

Figure 5.7.4. Panama sectoral emissions

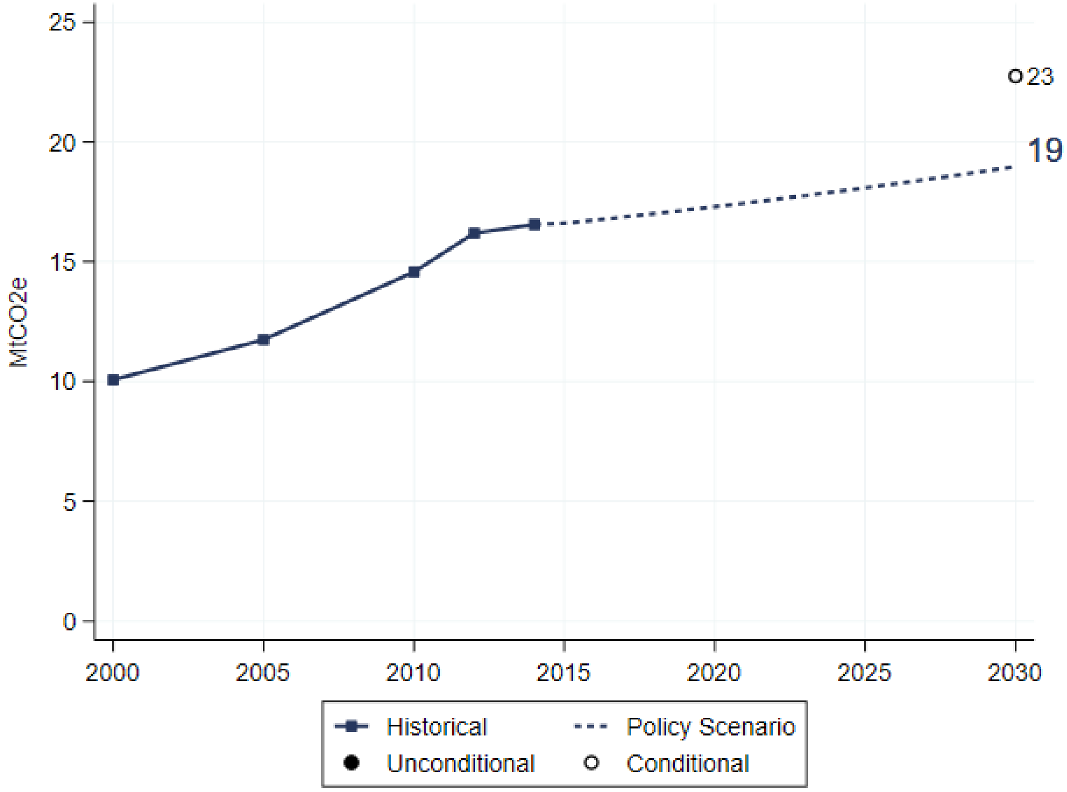

Figure 5.7.5. Panama total emissions

Table 5.7.1. Fuel shares and generation ratios for Panama

	Coal	Oil	Natural gas	Nuclear	Hydro	Wind/solar/ geothermal	Biofuels/ waste
2015: TPES Share	0.05	0.74	0	0	0.13	0.01	0.08
2015: Ratio - generation to TPES (GWh/ktoe)	3.41	0.90	0	0	11.63	0.00	0.11
Source: Calculations using IEA (2017a)							

Table 5.7.2. Projected growth rates for Panama

	Average Annual Growth Rates
GDP (2016–2030)	5.82%
TPES per GDP (2016–2030)	-4.40%
Population (2016–2030)	1.39%

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

5.8 Peru

Figure 5.8.1. Map of Peru

Peru is a Latin American country along the western coast of South America. It is bordered by Ecuador and Colombia to the north, Brazil and Bolivia to the east, and Chile to the south. Lima, Peru's capital city, is situated along the country's Pacific Ocean coastline in the west.

According to UN (2017), Peru had a population of 31.4 million people in 2015, or 5.99% of the total population in the LAM region. Peru's population grew an average of 1.28% annually from 2000 to 2015 (compared to the LAM rate of 1.24%) and is projected to grow at an average annual rate of 1.07% from 2016 through 2030 (compared to the LAM rate of 0.83%).

In 2015 the GDP of Peru was 483 billion Peruvian Nuevo sol (2007 prices). The country experienced an average annual growth rate of 5.31% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 4.28% average annual growth rate of GDP for 2016 to 2030.

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

We construct the Policy scenario by expanding generation capacity in parallel with Peru's New Sustainable Energy Matrix (NUMES) Objective plan (Ministerio del Ambiente, 2016) which specifies 11,833 MW of capacity additions between 2010 and 2030. In these expansion plans, hydropower contributes 52% of the capacity additions, thermal sources account for 25%, and unconventional renewables (wind, solar, geothermal, and biofuels) account for 23%. We model Peru's thermal capacity plans as an expansion in natural gas by 16% from 21,726 GWh in 2015 to 25,235 GWh in 2030. As of 2018, total hydropower potential in Peru is estimated at 70,000 MW, of which only 8% has been utilized (IHA, 2018). As indicated by the NUMES Objective, Peru intends to harness its hydropower resources to meet the country's growing demand for electricity, specifically through 39 new hydropower plants totaling 2,900 MW of capacity (IHA, 2018). Altogether, we project generation in 2030 reaches 92,471 GWh with 63% hydro, 27% natural gas, 6% wind/solar/geothermal, 2% biofuels/waste, and 1% oil. TPES in 2030 reaches 41,791 ktoe consisting of 45% oil, 27% natural gas, 12% biofuels/waste, 12% hydro, 2% wind/solar/geothermal, and 2% coal.

In the Policy scenario, Peru is projected to emit 137 $MtCO_2e$ excluding LULUCF emissions in the year 2030, with fossil fuel combustion contributing 65% of total modeled emissions. In its NDC, Peru pledges to reduce economy-wide emissions by 20% in 2030 relative to a BAU scenario, or by 30% conditional on international support. As CAT (2018) reports 77% of the unconditional reductions (and 71% of the conditional reductions) will come from the forestry sector alone, we adjust Peru's emissions targets to a 5% unconditional reduction and 9% conditional reduction from the BAU in 2030 to exclude LULUCF mitigation measures. We estimate these updated targets to be 139 $MtCO_2e$ unconditionally and 133 $MtCO_2e$ conditionally in 2030, which means that the Policy scenario surpasses the unconditional target by 1% of Policy emissions but still requires further reductions equal to 3% of Policy emissions in order to reach the conditional target.

Notably, Peru's NDC reports estimated BAU emissions of 139 $MtCO_2e$ in 2030 (excluding LULUCF), which equals MIT's estimate of Peru's unconditional target. This comparison—indicating that MIT's interpretation of Peru's energy policies aligns with Peru's reference path—reinforces that Peru is focusing on mitigation measures outside the generation sector to meet its Paris pledges.

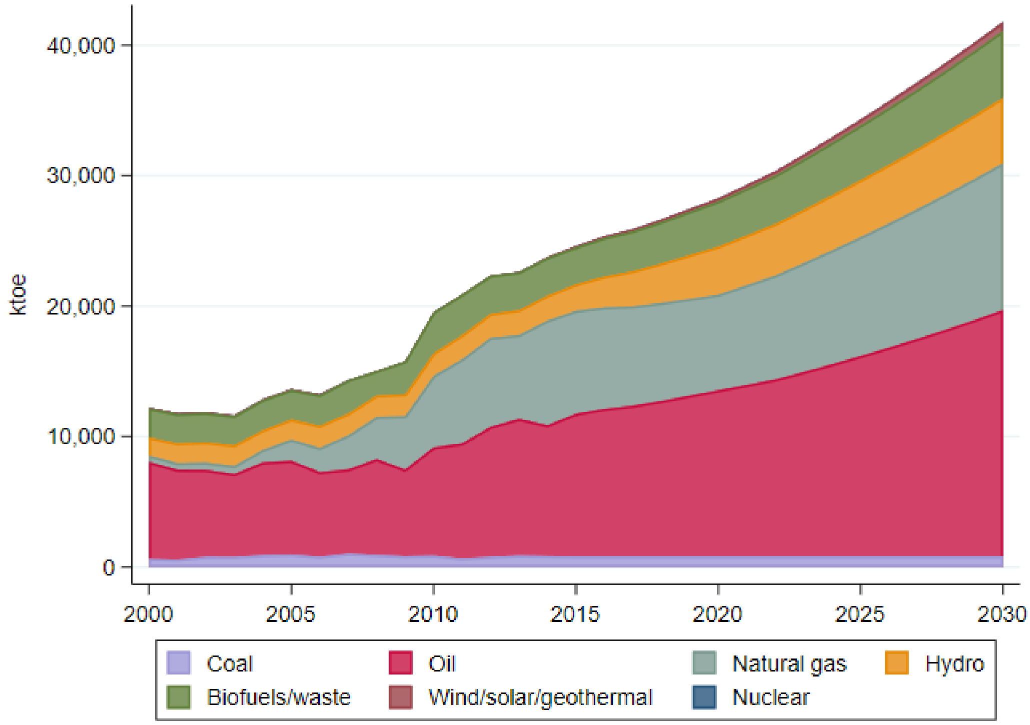

Figure 5.8.2. Peru Total Primary Energy Supply (TPES)

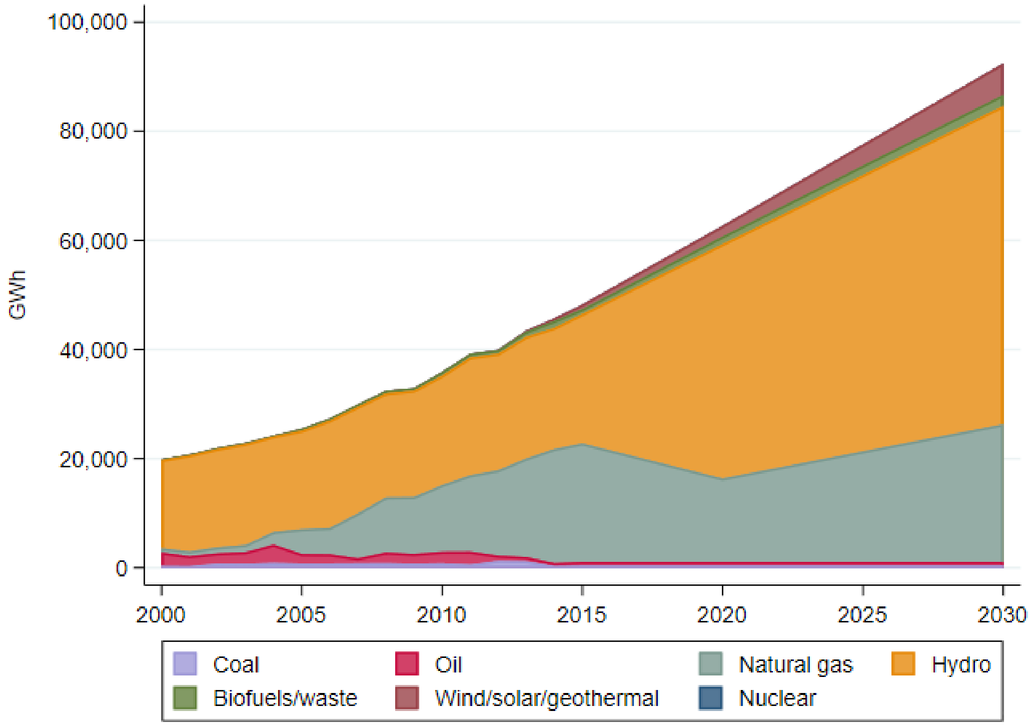

Figure 5.8.3. Peru electricity generation

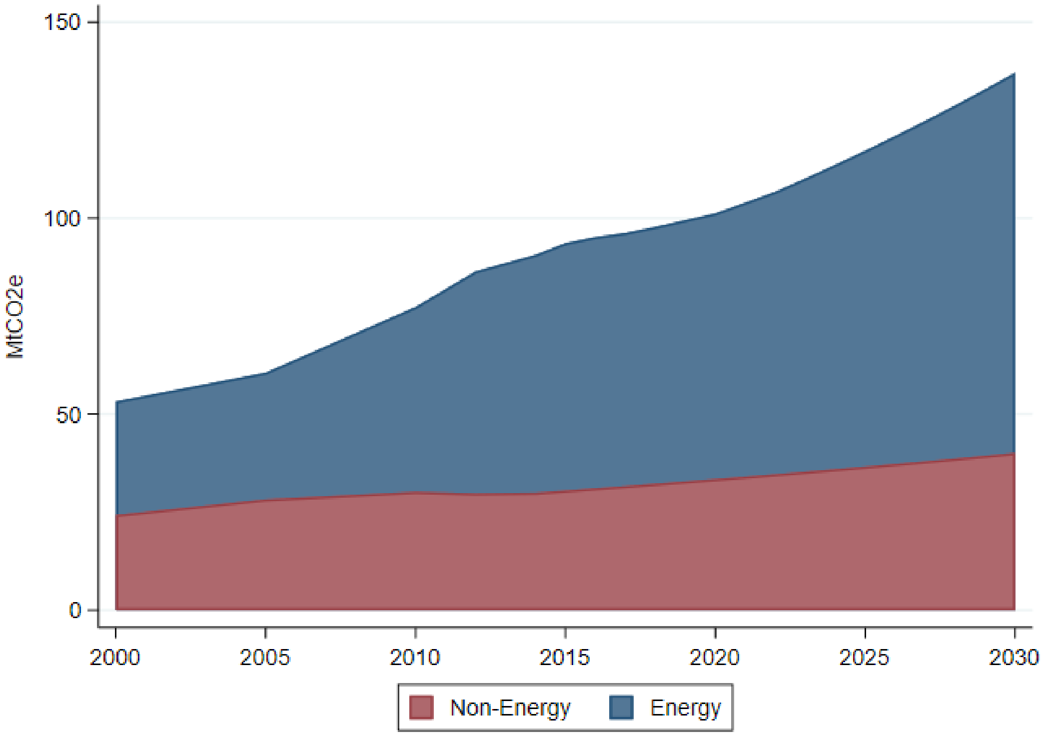

Figure 5.8.4. Peru sectoral emissions

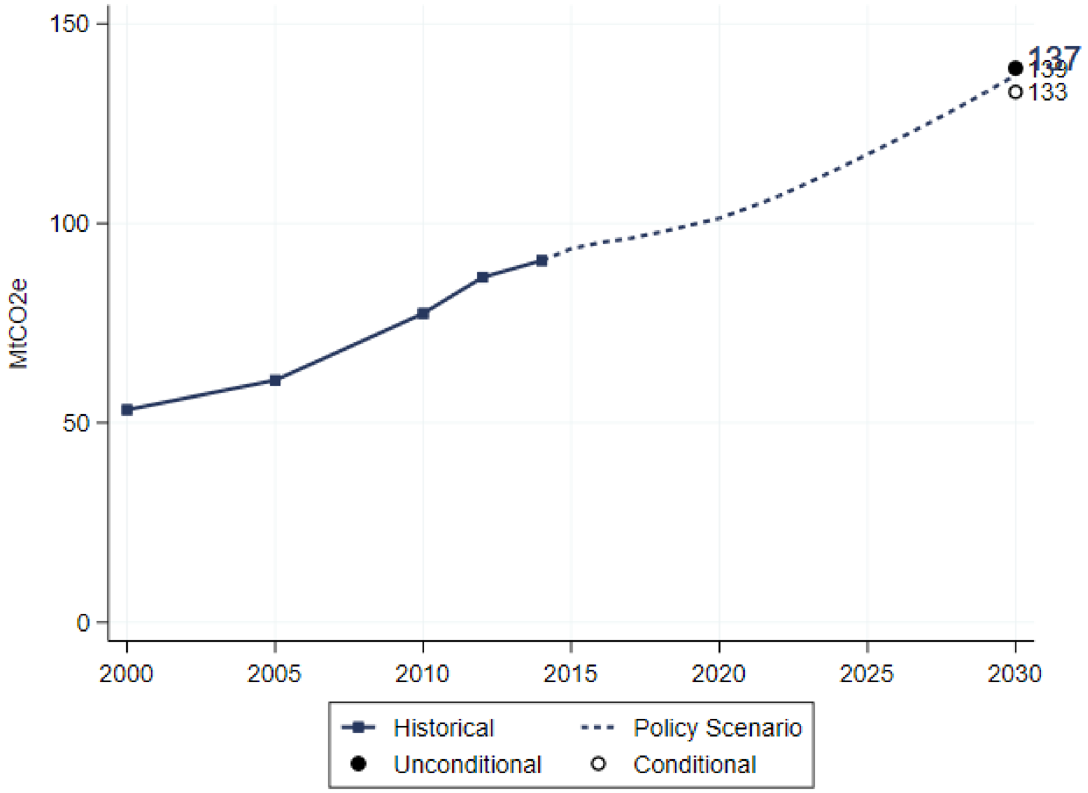

Figure 5.8.5. Peru total emissions

Table 5.8.1. Fuel shares and generation ratios for Peru

	Coal	Oil	Natural gas	Nuclear	Hydro	Wind/solar/ geothermal	Biofuels/ waste
2015: TPES Share	0.03	0.44	0.32	0	0.08	0.00	0.12
2015: Ratio - generation to TPES (GWh/ktoe)	0.50	0.06	2.75	0	11.63	8.54	0.32
Source: Calculations using IEA (2017a)							

Table 5.8.2. Projected growth rates for Peru in Policy scenario

	Average Annual Growth Rates
GDP (2016–2030)	4.28%
TPES per GDP (2016–2030)	-0.66%
Population (2016–2030)	1.07%

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

5.9 Uruguay

Figure 5.9.1. Map of Uruguay

Uruguay is a country in the southeastern region of South America. It is bordered by Brazil to the north, Argentina to the west, and the Atlantic Ocean to the east and south. Uruguay's capital city, Montevideo, is situated on the country's southern coast along Rio de La Plata and across the bay from Buenos Aires, the capital of Argentina.

According to UN (2017), Uruguay had a population of 3.4 million people in 2015, or 0.65% of the total population in the LAM region. Uruguay's population grew an average of 0.22% annually from 2000 to 2015 (compared to the LAM rate of 1.24%) and is projected to grow at an average annual rate of 0.31% from 2016 through 2030 (compared to the LAM rate of 0.83%).

In 2015 the GDP of Uruguay was 670 billion Uruguayan pesos (2005 prices). The country experienced an average annual growth rate of 3.26% from 2000 to 2015 (IMF, 2017). Based on IMF historical and projected data for 2000 to 2022, we adopt a 3.03% average annual growth rate of GDP for 2016 to 2030.

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

Under the Policy scenario, TPES in Uruguay reaches 7,468 ktoe in 2030 with a fuel makeup of 43% biofuels/waste, 38% oil, 9% hydro, 9% wind/solar/geothermal, and 1% natural gas. Total generation in 2030 is 20,365 GWh with 39% wind/solar/geothermal, 37% hydro, 14% biofuels/waste, and 10% oil. To reach these estimates, we model an 11% reduction in TPES from the Baseline scenario in 2030 to align with Uruguay's targeted 5% reduction in energy consumption in 2024 relative to its BAU, per the National Energy Efficiency Plan 2015-2024 (MIEM, 2015). We also expand renewable generation based on capacity goals specified in Uruguay's NDC, with 1,450 MW wind, 220 MW solar and 410 MW biomass added by 2025. Hydropower potential in Uruguay has been largely utilized (IHA, 2017), so we maintain hydro generation at the 2015 levels.

In its Policy scenario, Uruguay is projected to emit 53 $MtCO_2e$ excluding LULUCF emissions in the year 2030, with emissions from fossil fuel combustion contributing 18% of total modeled emissions. In its NDC, Uruguay provides official 2025 pledges and intended 2030 targets for emissions intensities relative to both economic performance and food production. With a focus on the emissions intensity of GDP goals for 2030, we model Uruguay's unconditional (conditional) NDC targets as a 27% (31%) reduction in CO_2 emissions intensity, 62% (63%) reduction in CH_4 emissions intensity, and 51% (57%) reduction in N_2O emissions intensity relative to 1990. These pledges yield estimated emissions targets of 54 $MtCO_2e$ unconditionally and 51 $MtCO_2e$ conditionally in 2030. Therefore, the Policy scenario trajectory more than achieves both target levels with a 2030 emissions gap of less than 1 $MtCO_2e$ unconditionally and 3 $MtCO_2e$ conditionally.

In addition to expanding its non-hydro renewables generation, Uruguay aims to electrify its transport sector with improved public transport and utility fleets and by building up its power infrastructure to support electric vehicles along the national corridors.

To meet these emissions goals in the energy sector, in addition to expanding its non-hydro renewables generation, Uruguay aims to electrify its transport sector with improved public transport and utility fleets and by building up its power infrastructure to support electric vehicles along the national corridors. The country is targeting the residential sector with several energy efficiency measures, including through the 2024 Energy Efficiency Plan's improved regulation, verification, and certification of green appliances and homes.

Beyond the energy sector, Uruguay intends to adopt additional measures in the agriculture, industry, and waste sectors, as well as in land conservation. As beef production accounts for 83% of the GHG emissions from agriculture, Uruguay aims to pursue its mitigation goals without threatening food production. Cited in Uruguay's NDC, the Climate-Smart Agriculture Policy of 2010, for example, includes measures to support herd efficiency and to preserve natural grasslands, thereby protecting the natural carbon stock in soils and decreasing methane emissions by improving the quality and digestibility of cattle diets. As less than one-fifth of the country's projected emissions come from the energy sector, Uruguay's overall mitigation performance will largely be determined by these agricultural policies and practices.

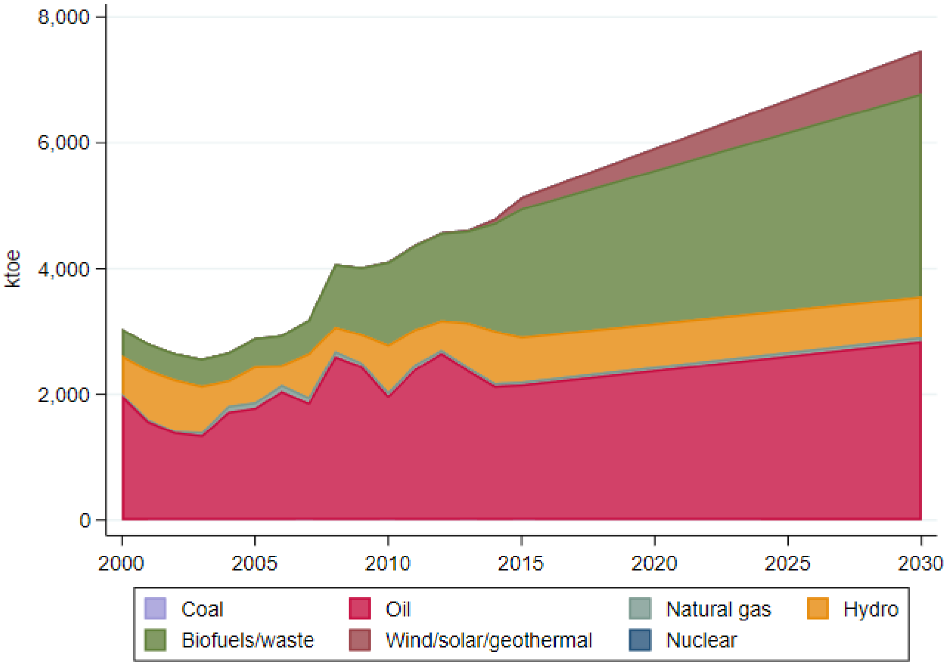

Figure 5.9.2. Uruguay Total Primary Energy Supply (TPES)

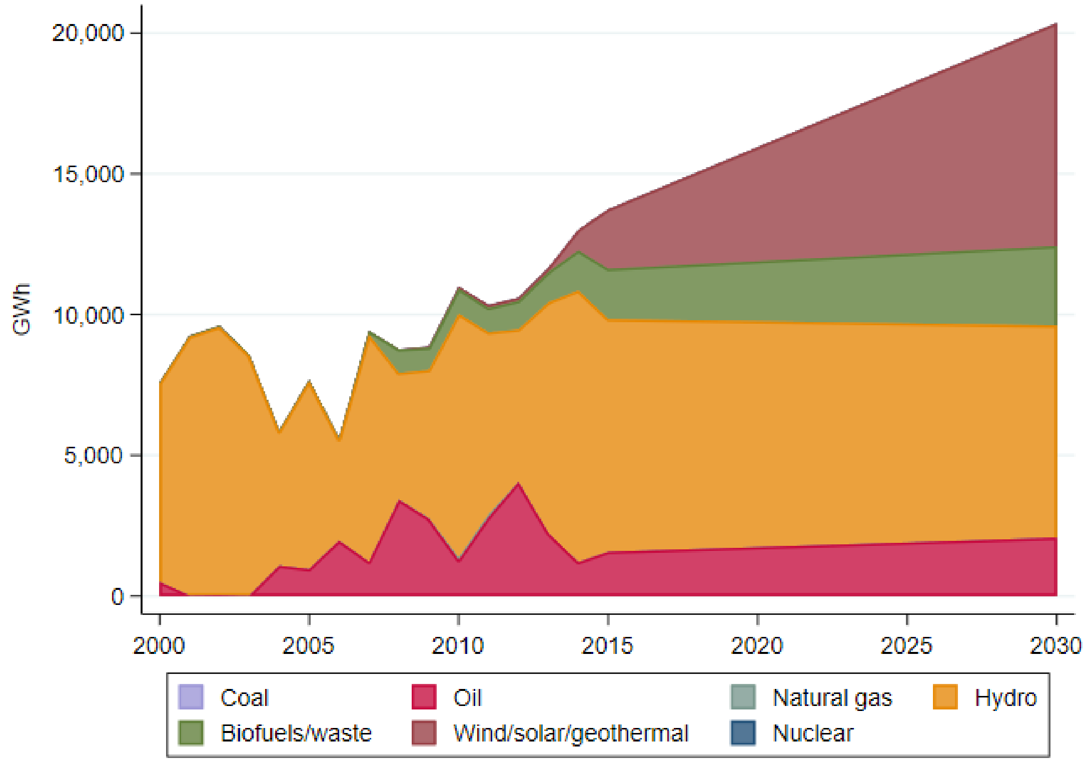

Figure 5.9.3. Uruguay electricity generation

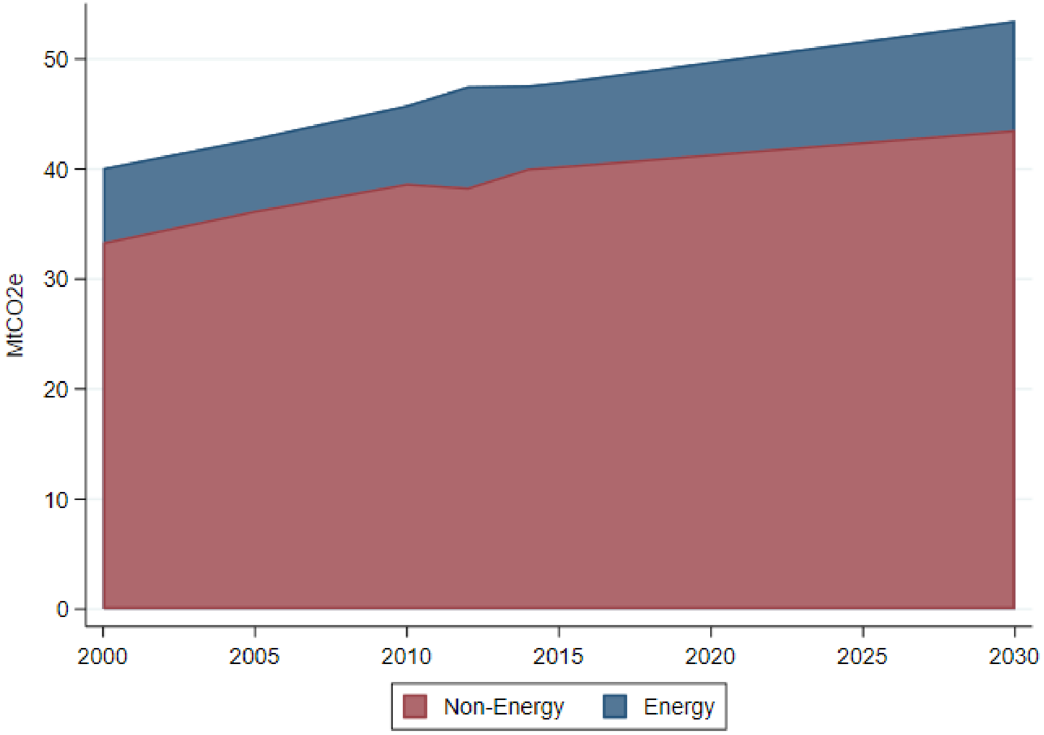

Figure 5.9.4. Uruguay sectoral emissions

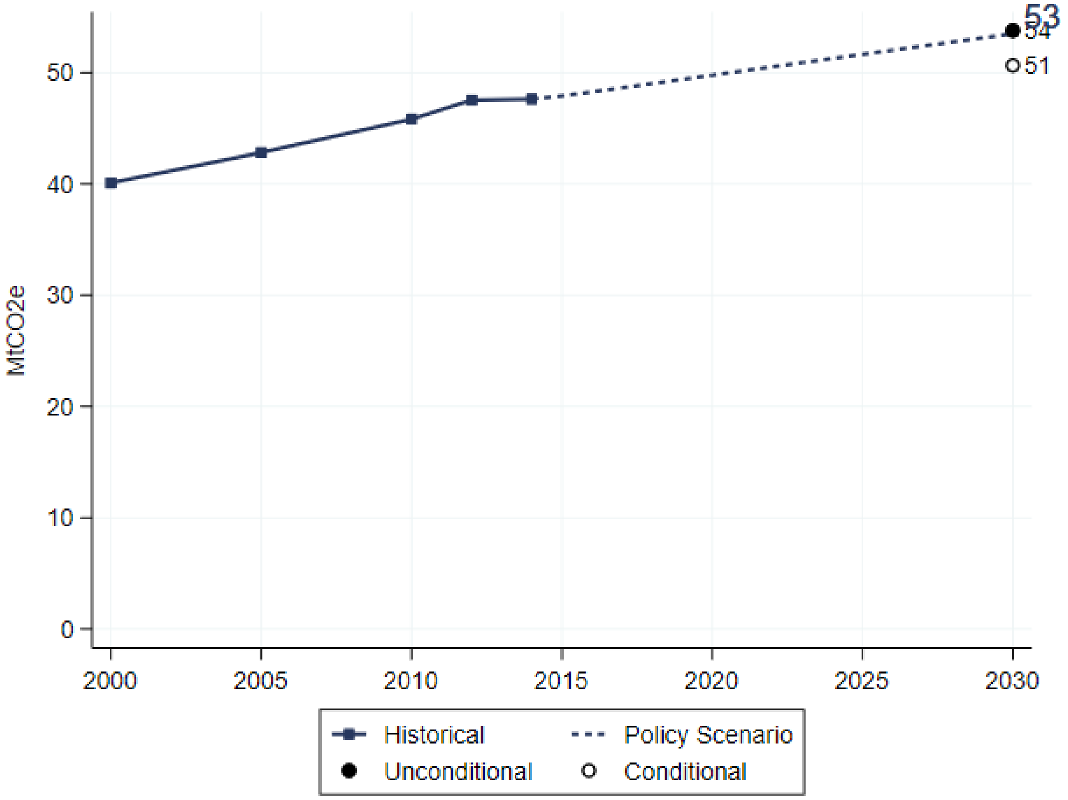

Figure 5.9.5. Uruguay total emissions

Table 5.9.1. Fuel shares and generation ratios for Uruguay

	Coal	Oil	Natural gas	Nuclear	Hydro	Wind/solar/ geothermal	Biofuels/ waste
2015: TPES Share	0	0.42	0.01	0.00	0.14	0.04	0.40
2015: Ratio - generation to TPES (GWh/ktoe)	0	0.73	0.00	3.84	11.63	11.63	0.87
Source: Calculations using IEA (2017a)							

Table 5.9.2. Projected growth rates for Uruguay

	Average Annual Growth Rates
GDP (2016–2030)	3.03%
TPES per GDP (2016–2030)	-0.49%
Population (2016–2030)	0.31%

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

5.10 Venezuela

Figure 5.10.1. Map of Venezuela

Venezuela is a country in the northern part of South America. It borders Colombia to the west, Brazil to the south, Guyana to the east, and the Caribbean Sea to the north. Venzuela's capital city, Caracas, is situated on the country's Caribbean coastline.

According to UN (2017), Venezuela had a population of 31.2 million people in 2015, or 5.95% of the total population in the LAM region. Venezuela's population grew an average of 1.62% annually from 2000 to 2015 (compared to the LAM rate of 1.24%) and is projected to grow at an average annual rate of 1.11% from 2016 through 2030 (compared to the LAM rate of 0.83%).

In 2015 the GDP of Venezuela was 56.1 billion Venezuelan bolívares fuertes (1997 prices). The country experienced an average annual growth rate of 2.11% from 2000 to 2015 (IMF, 2017). While the country has experienced a recession since 2013, we optimistically adopt an 3.26% average annual growth rate of GDP for 2016 to 2030 under the assumption that the economy takes a positive turn in 2018.

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

We incorporate renewables from Venezuela's Development Plan for the National Electric System into the Policy scenario for this country. The country intends to develop 613 MW of renewables, including 500 MW of wind, plus some small hydro and bioenergy resources. The plan also includes an additional 63 MW of solar and hybrid systems to help electrify off-grid communties. Taking these plans into consideration, we model generation in 2030 as 124,164

GWh from 70% hydro, 18% natural gas, 10% oil, and 1% wind/solar/geothermal. TPES in 2030 is 77,895 ktoe with 53% oil, 36% natural gas, 10% hydro, and 1% biofuels/waste.

In the Policy scenario, Venezuela is projected to emit 309 $MtCO_2e$ excluding LULUCF emissions in the year 2030, with fossil fuel combustion contributing 75% of total modeled emissions. In its NDC, Venezuela pledges to reduce economy-wide emissions by 20% in 2030 relative to a BAU scenario, conditional on international support. We estimate this emissions target as 293 $MtCO_2e$ in 2030, which means that the energy sector measures incorporated in the Policy scenario yield a remaining 16 $MtCO_2e$ (5% of Policy secenario emissions) of additional reductions needed.

To further close the emissions gap, Venezuela is considering mitigation measures outside of the generation sector. In the area of transportation, Venezuela is developing an improved inter-city bus system, and within urban areas, is creating 45 new public transportation systems to provide a total of 329 new service routes. In the area of energy efficiency, Venezuela aims to reduce the energy and material needs of its manufacturing industries, as well as in the the energy-intensitve exploration and production practices of its oil industry. Venezuela also envisions a nation-wide educational campaign, including within grade schools, to encourage more energy efficient practices.

> *Venezuela is also considering mitigation measures outside of the generation sector, including in public transportation, improved energy efficiency in certain industries, and a nation-wide educational campaign to encourage more energy efficient practices.*

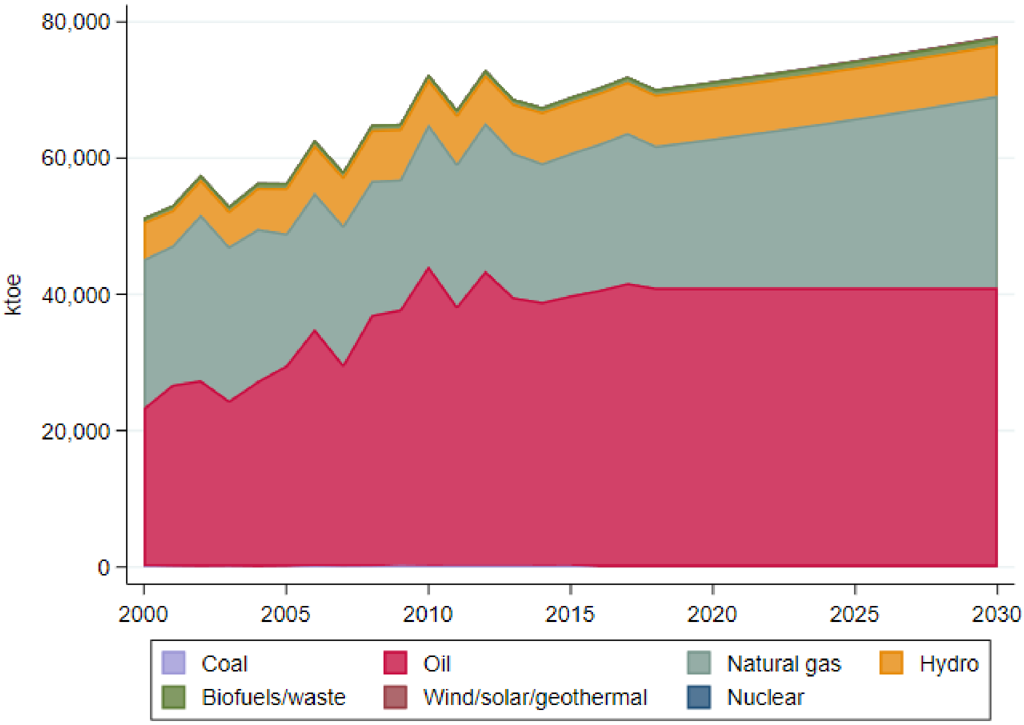

Figure 5.10.2. Venezuela Total Primary Energy Supply (TPES)

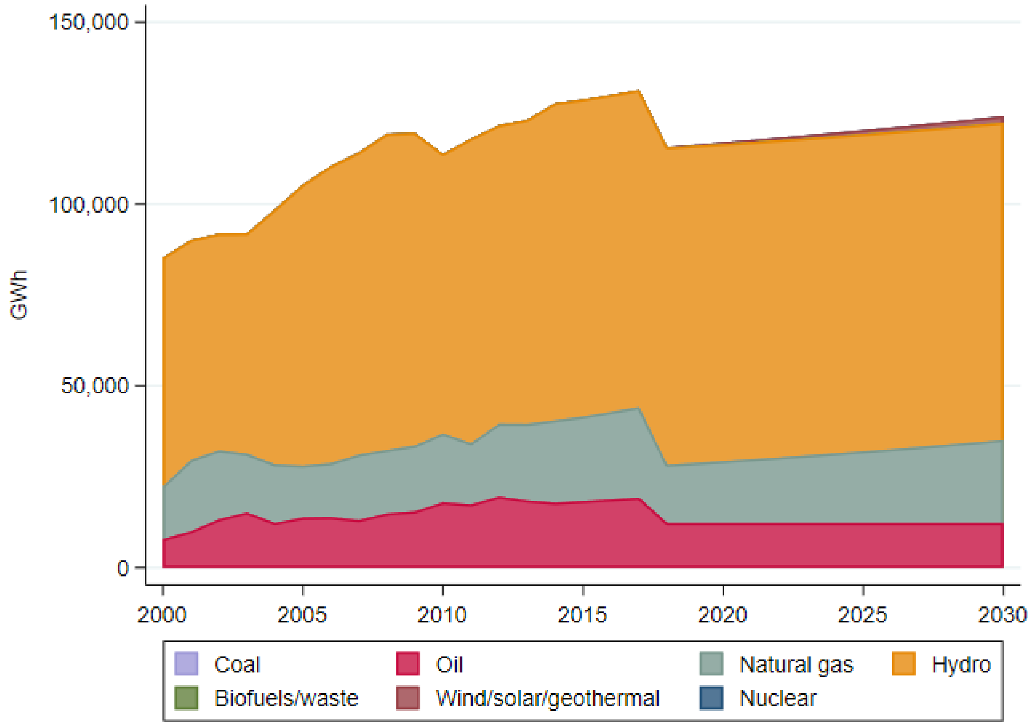

Figure 5.10.3. Venezuela electricity generation

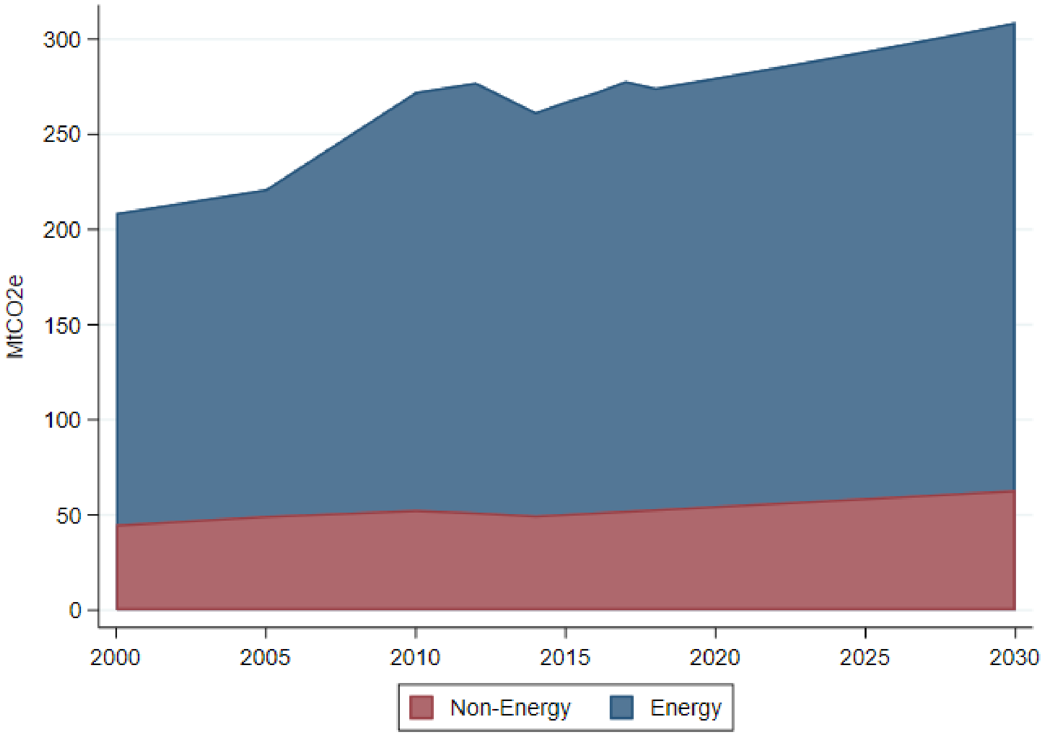

Figure 5.10.4. Venezuela sectoral emissions

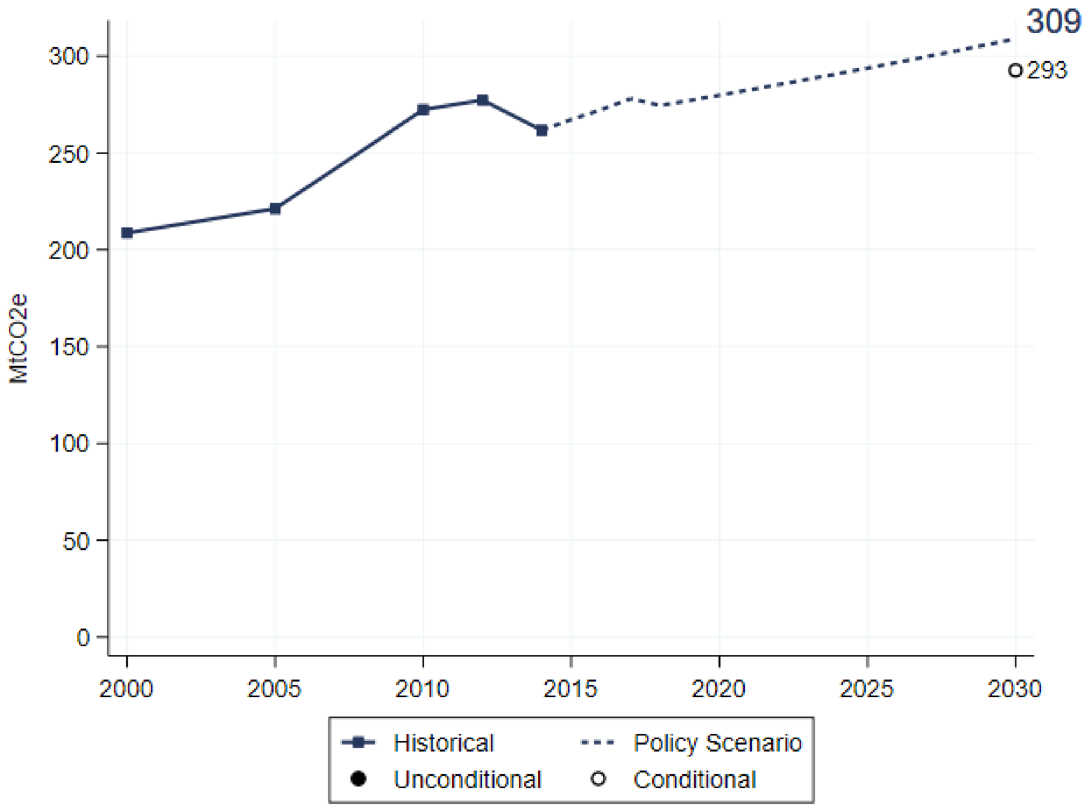

Figure 5.10.5. Venezuela total emissions

Table 5.9.1. Fuel shares and generation ratios for Venezuela

	Coal	Oil	Natural gas	Nuclear	Hydro	Wind/solar/ geothermal	Biofuels/ waste
2015: TPES Share	0	0.42	0.01	0	0.14	0.04	0.40
2015: Ratio - generation to TPES (GWh/ktoe)	0	0.46	1.11	0	11.63	0.00	0.00

Source: Calculations using IEA (2017a)

Table 5.9.2. Projected growth rates for Venezuela

	Average Annual Growth Rates
GDP (2016–2030)	3.03%
TPES per GDP (2016–2030)	-0.49%
Population (2016–2030)	0.31%

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

6 Economy-wide Analyses for Argentina and Colombia

Main Takeaways

- Existing plans for the expansion of non-fossil electricity generation are sufficient to meet unconditional emission reduction targets in Argentina and Colombia.
- Conditional emissions reduction pledges can be achieved with moderate additional policies. For example, when non-fossil electricity targets are met, the addition of an all-sectors ETS that caps emissions at the level consistent with each nation's conditional pledge results in carbon prices in Argentina and Colombia of, respectively, of \$2.7 and \$2.9 per tCO_2e.
- GHG emission mitigation efforts should be based on economy-wide coverage rather than on selected sectors of the economy.
- Adding a renewable portfolio standard to target a specified share of electricity from non-fossil sources to an all-sectors ETS increases the cost of reducing emissions (even though it reduces the carbon price).
- 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 Argentina and Colombia. 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.

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 models relative to energy system models such as the MARKet Allocation (MARKAL) and The Integrated MARKAL-EFOM System (TIMES) models (Loulou *et al.*, 2004) is that they consider economic activity and GHG emissions in all sectors. This feature is salient for Latin American nations, as a significant proportion of emissions result from activities outside electricity and energy-intensive sectors in many countries, including Argentina and Colombia.

6.1 Modeling Framework

The sectoral aggregation of the model 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, nuclear (for Argentina only) and other renewables. The model also represents five energy-intensive sectors (chemical, rubber, and plastic products; non-metallic minerals; iron and steel; non-ferrous metals; and fabricated metal products) 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.

Table 6.1. Sectoral aggregation

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

*Only included for Argentina.

6.2 Policy and Technology Scenarios

We implement six 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.

Table 6.2. Scenarios

Name	Description
BAU	Selected economy in 2030 under 'Business as usual' (no climate policies)
RPS	Renewable portfolio standard to set proportion of non-fossil electricity in total generation
CON-ALL	RPS and conditional (CON) emissions target using an ETS on all sectors
CON-SEL	RPS and conditional emissions target using an ETS on selected sectors
CON-ETS	Conditional emissions target using an ETS on all sectors (without RPS)
CON-ALL-DIG	CON-ALL with increased adoption of digitalization (DIG)

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 2.55% for Argentina, and 3.85% for Colombia. 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, 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.

The five policy scenarios simulate energy/climate policies. As both nations have goals to significantly increase power generation from non-fossil sources, the first policy scenario, simulates a renewable portfolio standard (RPS) to set a minimum share for electricity generation from non-fossil sources in total generation. For Argentina, following the 'Trend+Investment 2030' scenario reported by MINEM (2017), we specify that non-fossil electricity must contribute at least 62% of total power generation. For Colombia, guided by UPME (2016), the share of non-fossil electricity in total power generation must be at least 87%.[1]

Remaining scenarios, in addition to RPS constraints (in most cases), simulate various emissions trading systems (ETSs) to meet each country's conditional NDC pledge.[2] Countries may chose alternative policies to meet NDC targets. We focus on ETSs as such systems are widely acknowledged as 'first best' (i.e., least-cost) policies and focus our analysis on (1) the sectoral scope of the system, and (2) the adoption of alternative technologies. This is achieved by designing scenarios that differ with respect to (1) the sectoral coverage of the ETS, and (2) the adoption of digitalization in electricity generation.

Estimated national emissions excluding those from LULUCF consistent with unconditional and conditional targets in 20303 in each region are reported in Table 6.3. Estimates for Argentina are sourced from CAT (2018). For Colombia, non-LULUCF emissions consistent with this nation's conditional target are estimated by combining forecasted BAU emissions from (Colombia NDC, p. 3) and planned reductions in emissions from deforestation from Colombia's Third National Communication to the UNFCCC (IDEAM *et al.* 2017), as detailed in Appendix E, Section E.2.

Table 6.3. National emissions consistent with unconditional and conditional Paris pledges, $MtCO_2e$, Excluding emissions from LULUCF.

	Unconditional	Conditional
Argentina	405.0	310.0
Colombia	214.6	181.4

Source: Estimated for Argentina are from CAT (2018). Methods used to estimate targets for Colombia are described in Appendix E.

In the CON-ALL scenario, in addition to the RPS target, an ETS covering ALL sectors (and GHGs) is imposed to meet each nation's CONditional emissions target. The CON-SEL imposes the same policies as the CON-ALL scenario, except that the ETS only includes SELected sectors; namely, electricity sectors, energy-intensive industries (chemical, rubber, and plastic products; non-metallic minerals; iron and steel; non-ferrous metals; and fabricated metal products), and refined oil products, and there are no regulations on emissions from other sectors.

In the CON-ETS scenario, conditional emission targets are enforced using an ETS on all sectors without targets for non-fossil electricity generation. Comparing results for the scenario to those from the CON-ALL scenario facilitates a comparison of the impacts of regulations (i.e., the RPS) with the effects of a market-based measure (i.e., an ETS).

The final scenario, CON-ALL-DIG, assess the impact of increased DIGitalization in the electricity sector. It imposes the same policy measures as the CON-ALL scenario and assumes that relative to BAU, increased adoption of digitalization increases energy conversion efficiency in fossil power generation by 5%; and increases the penetration of other renewable electricity by 10%.[3] Our digitalization-induced efficiency improvements in fossil generation are informed by estimates by Annunziata and Bell (2015). For renewables, (GE, 2018) notes that GE's Digital

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[1] We model the RPS using a certificate system where non-fossil electricity generators are awarded a certificate for each kWh of power produced, and all electricity producers are required to hand in a specified number of certificates per kWh of electricity sold. For Argentina and Colombia, electricity producers are required to submit, respectively, 0.62 and 0.87 certificates for each kWh of electricity sold.

[2] We do not use an ETS to impose unconditional targets as our simulations indicate that the non-fossil electricity targets in the RPS scenario will result in fewer emissions than in each nation's unconditional pledge (see Sections 6.3 and 6.4 for more details).

[3] 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.

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.

6.3 Results for Argentina

Modeling Results

- Existing plans for the expansion of non-fossil electricity generation are sufficient to meet Argentina's unconditional emissions reduction target.
- Argentina's conditional emissions pledge can be achieved with moderate additional policies. For example, when non-fossil electricity targets are met using an RPS, the addition of an all-sectors ETS that caps emissions at the level consistent with Argentina's conditional pledge results in a carbon price of \$2.7/tCO_2e and increases the reduction in GDP from 0.16% to 0.17%.
- However, if the ETS only includes electricity and energy-intensive sectors, the required carbon price is much larger and the GDP costs are much greater. For example, under such an ETS, the carbon price is \$158.9 and the reduction in GDP is 0.70%. This is because emissions from electricity and energy-intensive sectors only account for only a quarter of total emissions, so a large proportional reduction in emissions from these sectors is required to meet the economy-wide emissions target.
- Although a RPS to meet non-fossil electricity generation targets lowers the carbon price, it increases the GDP cost of reducing emissions. For example, when meeting Argentina's conditional emission reduction pledge using an all-sectors ETS, removing the RPS increases the carbon price from \$2.7 to \$16.7 and deceases the reduction in GDP from 0.17% to 0.06%. This is because the RPS only reduces emissions in the electricity sector by a specific means, while an ETS incents emission reductions wherever and however they are cheapest.
- Increased adoption of digitalization in electricity generation lowers the cost of meeting emission reduction targets. For example, when a RPS and an economy-wide ETS is used to meet Argentina's conditional target, digitalization lowers the reduction in GDP from 0.17% to 0.08%.

A summary of results for Argentina is reported in Table 6.4, with additional results in Figures 6.2 (GHG emissions), 6.3 (electricity generation), 6.4 (primary energy), and Table 6.5 (sectoral output changes for selected scenarios).[4] In the BAU scenario, the imposed level of GDP in 2030 is \$877.9 billion (in 2011 dollars), an increase of 61.4% relative to 2011. Total GHG emissions in 2030 are 378.9 $MtCO_2e$, a 12.6% increase relative to 2011. The GHG intensity of GDP, therefore, decreases by 30.2% between 2011 and 2030. Electricity generation and primary energy use in 2030 are, respectively, 306.6 TWh and 111.2 Mtoe.

In the RPS scenario, the mandate for non-fossil electricity increases generation from other renewables from 48.3 TWh to 54.4 TWh, a 12.8% increase. At the same time, the requirement for fossil generators to purchase renewable electricity certificates increases costs for these producers and ultimately reduces generation from gas and coal by, respectively, 56.8% and 40.9% relative to BAU. Economy-wide emissions (excluding LULUCF) in the RPS scenario in 2030 are 352.3 $MtCO_2e$, below the level consistent with Argentina's unconditional Paris pledge (405.0) but above this nation's conditional pledge (310.0). Higher electricity costs/prices due to the RPS, relative to BAU, reduce total electricity production by 29.7%, and non-ferrous metals (primarily aluminum) production by 12.3% (Table 6.5). At an aggregate level, the RPS mandate reduces GDP by 0.16% relative to BAU.

In the CON-ALL scenario, in addition to the RPS, a carbon price of \$2.7/tCO_2e applied in all sectors is required to reduce 2030 emissions to 310.0 $MtCO_2e$. Under the modest carbon price,

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[4] Results displayed in Figures 6.2–6.4 are presented in tables in Appendix E.

electricity production is similar to that in the RPS scenario, and GDP is only slightly lower.

When the conditional target is met using an ETS on selected energy and energy-intensive sectors, as in the CON-SEL scenario, the carbon price is significantly higher, \$158.9/tCO$_2$e. This is because, in the RPS scenario, emissions from selected sectors account for only 25% of total emissions, so the carbon price has to incent a large proportional reduction in emissions from these sectors to meet the economy-wide emissions target. That is, relative to the RPS scenario, the selected ETS sectors reduce their emissions by 46% in order to reduce total emissions by 12%. The carbon price results in significant reductions in electricity from coal and gas (Figure 6.2) and large proportional reductions in output from other selected sectors, especially non-ferrous metals and iron and steel (Table 6.5). The selected sectors ETS also significantly increases the GDP costs of meeting the conditional emissions target relative to when an ETS is applied to all sectors (i.e., relative to BAU, GDP decreases by 0.17% in the CON-ALL scenario and 0.70% in the CON-SEL scenario).

In the CON-ETS scenario, the all-sectors ETS without a RPS results in a carbon of \$16.7/tCO$_2$e. This is higher than in the CON-ALL scenario, where there is an all-sectors ETS and a RPS, (\$2.7). The carbon price is lower when there is a RPS as the ETS has to reduce emissions by a smaller amount this scenario—the ETS reduces emissions by 42.3 MCO$_2$e (352.3 – 310.0) when there is a RPS and 68.9 MCO$_2$e (378.9 – 310.0) without a RPS. However, the RPS does not ensure that emissions are reduced at least-cost and the carbon price is a misleading indictor of the cost policy costs. This is because the RPS forces the economy to reduce emissions in a specific sector in a specific way (increasing the share of electricity from non-fossil sources), while an ETS without this regulation incents emissions reductions wherever and however they are cheapest. As a result, the 2030GDP cost (relative to BAU), of meeting the conditional emissions target without the RPS (\$0.5 billion) is lower than when there is a RPS (\$1.5 billion).

The absence of the RPS results in more electricity from fossil fuels and total electricity in the CON-ETS scenario relative to the CON-ALL scenario (Figure 6.3). To compensate for more emissions from electricity generation, emissions from non-electricity sectors reduce emissions by reducing their output (Table 6.5) and improving efficiency.

The impact of increased digitalization in the electricity sector can be evaluated by comparing results for the CON-ALL-DIG and CON-ALL scenarios. The results indicate that increased digitalization lowers the cost of meeting the emissions constraint (i.e., GDP is \$0.8 billion higher in the CON-SEL-DIG scenario than in the CON-ALL scenario), and lowers the carbon price (from \$2.7 to \$2.5).[5] More extensive adoption of digitalization also increases total electricity generation from 215.5 to 223.4.9 to 219.4 TWh, with the increased generation mainly from gas and other renewables. Overall, results for the CON-ALL-DIG scenario reveals that, if it is cost effective, increased digitalization could help lower the cost of reducing emissions in Argentina.

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[5] 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.

Table 6.4. Argentina: Summary results in 2030

	BAU	RPS	CON-ALL	CON-SEL	CON-EST	CON-ALL-DIG
GDP billion 2011\$	877.9	876.5	876.5	871.8	877.4	877.2
GDP % change	-	-0.16%	-0.17%	-0.70%	-0.06%	-0.08%
CO_2 price 2011\$/tCO_2e	-	-	2.7	158.9	16.7	2.5
GHG emissions MtCO_2e						
Selected sectors	118.1	88.4	83.6	47.8	100.8	83.3
Other sectors	260.8	263.8	226.5	262.2	209.2	226.7
All sectors	378.9	352.3	310.0	310.0	310.0	310.0
Elec. generation TWh	306.6	215.5	215.5	167.0	283.5	223.4
Primary energy Mtoe*	111.2	100.6	99.9	84.4	104.5	100.3

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. Argentina: Output changes in 2030 relative to BAU, 2011\$ and %

	RPS		CON-ALL		CON-SEL	
	\$, b	%	\$, m	%	\$, b	%
Crude oil	0.014	0.1%	0.004	0.0%	-0.189	-0.9%
Refined oil products	0.050	0.2%	0.015	0.1%	-0.667	-2.6%
Natural gas extraction & dist.	-0.001	0.0%	-0.001	-0.1%	-1.200	-48.5%
Coal electricity	-0.350	-40.9%	-0.368	-43.0%	-0.776	-90.7%
Gas electricity	-1.573	-56.8%	-1.568	-56.6%	-2.277	-82.1%
Oil electricity	0.000	0.0%	0.000	0.0%	0.000	0.0%
Nuclear 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	0.254	12.8%	0.252	12.7%	0.246	12.4%
Electricity transmission & distrib.	-0.048	-24.4%	-0.049	-24.4%	-0.078	-39.4%
Agriculture	0.045	0.1%	-0.021	0.0%	0.261	0.3%
Other mining	-0.231	-2.6%	-0.234	-2.6%	-0.414	-4.7%
Chemical, rubber & plastic prod.	-1.076	-1.6%	-1.109	-1.7%	-4.205	-6.3%
Non-metallic minerals	-0.082	-0.7%	-0.094	-0.8%	-0.640	-5.4%
Iron and steel	-0.709	-6.2%	-0.727	-6.3%	-1.743	-15.2%
Non-ferrous metals	-1.482	-12.3%	-1.502	-12.5%	-2.824	-23.5%
Food processing	0.066	0.1%	0.000	0.0%	0.297	0.2%
Motor vehicles and parts	-0.323	-1.0%	-0.319	-1.0%	0.658	2.0%
Other manufacturing	-1.529	-1.2%	-1.547	-1.2%	-2.400	-1.9%
Transportation	-2.319	-0.7%	-1.413	-0.5%	-3.813	-1.2%
Services	-2.911	-0.1%	-7.147	-0.3%	-5.135	-0.2%

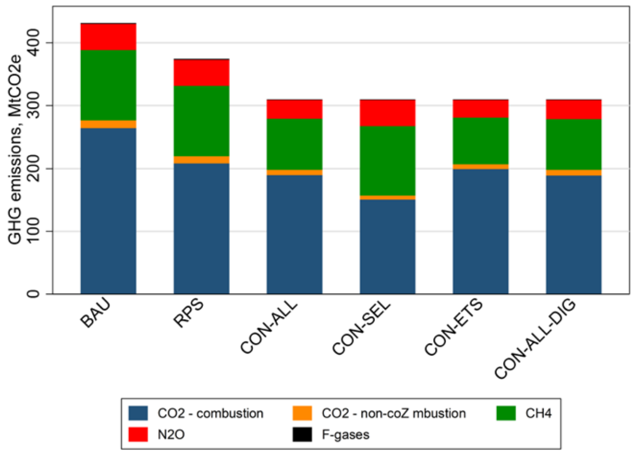

Figure 6.1.

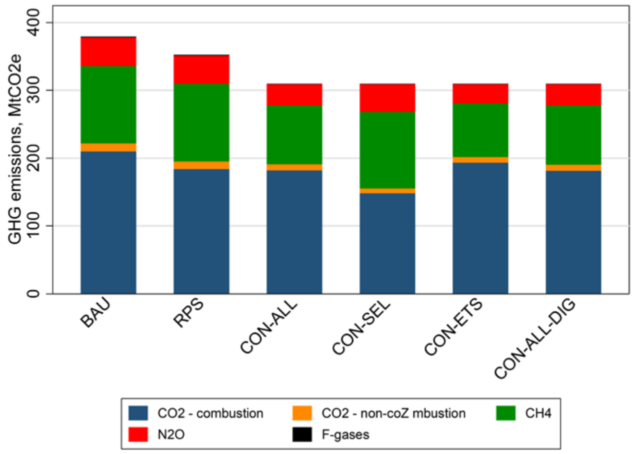

Figure 6.2. Argentina: GHG emissions in 2030, $MtCO_2e$

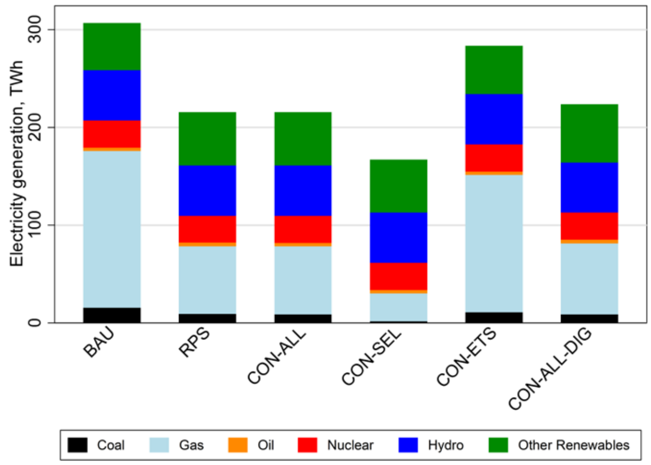

Figure 6.3. Argentina: Electricity generation in 2030, TWh

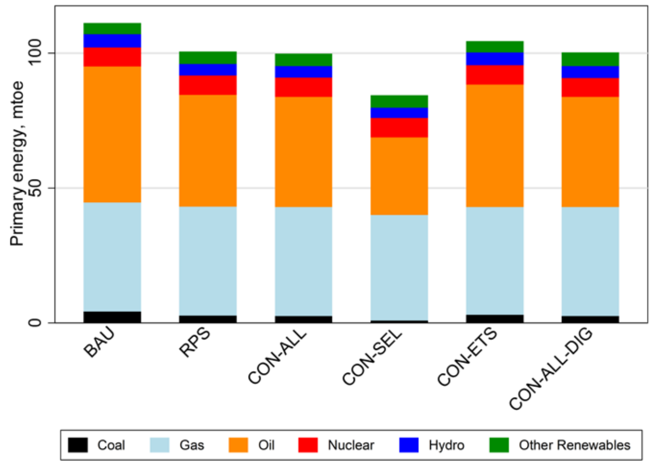

Figure 6.4. Argentina: Primary energy in 2030, Mtoe

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.

6.3.1 Policy Recommendations for Argentina

Main Takeaways

- With around 75% of generation capacity in private ownership, Argentina is already one of the most deregulated electricity markets in Latin America, and recently has made important progress in reforming its market for electricity and gas by liberalizing electricity and gas pricing.
- Future emissions growth in Argentina will largely center in the energy sector. Rapid growth in electricity demand and related power sector emissions, coupled with a relatively ambitious NDC, offer a significant opportunity for renewable energy deployment.
- Abundant shale gas reserves offer an opportunity to simultaneously address energy security concerns and provide a dispatchable, lower-carbon bridge fuel to balance the growing share of renewables in electricity generation until battery storage is economically more viable.
- Care must be taken to develop shale gas resources responsibly, addressing environmental impacts such as methane leakage, and considering the longer term evolution of the national and global energy system over time.
- The recent introduction of a carbon tax, effective in January 2019, may help investors to align investment strategies with decarbonization pathways. Over time, Argentina should consider expanding the scope of the carbon price to cover the economy at large, and increasing the tax rate to a level more consistent with the estimated social cost of carbon.

Argentina has made considerable progress with its energy and climate policies in recent years, deregulating gas and electricity prices, strengthening its policies to accelerate growth of renewable energy, and introducing a carbon tax on fossil fuels. Robust implementation of the RenovAr auctioning platform (including the penalties for delays and default on contracted terms), continued expansion of electricity transmission infrastructure and grid interconnections, responsible development of its abundant shale gas reserves, and further expansion of the carbon price are all recommended for continued decarobinzation in line with Argentina's NDC pledge.

Argentina was the first country to revise and strengthen its NDC following the election of President Mauricio Macri (Hübner, 2017). Unveiled at COP22 in 2016, the revised NDC is significantly more ambitious than the original pledge, partially due to a changed methodology for quantifying historical emissions data (UN Environment, 2017). This step signalled a reversal of how prior governments had approached climate change, affording it limited weight relative to the priority of economic recovery and social development after the crisis of 2001. For much of the decade, scarcity of capital, price-distorting subsidies, and political risk combined to make Argentina a relatively unappealing destination for clean energy investment (Bloomberg New Energy Finance, 2017). Under the new government, legal and administrative reforms to strengthen institutional capacity, rebuild investor trust, and liberalize energy markets offer a unique opportunity to advance Argentina's climate policy performance.

Institutionally, the new government has upgraded the executive agency responsible for environmental protection to the level of ministry, designating it the Ministry of Environment and Sustainable Development (Ministerio de Ambiente y Desarrollo Sustentable, or MAyDS). Within the ministry, climate change falls into the purview of the Office of the Undersecretary of Climate Change and Sustainable Development (Subsecretaría de Cambio Climático y Desarrollo Sustentable) and the newly established National Directorate of Climate Change (Dirección Nacional de Cambio Climático, or DNCC). Also newly created is an National Cabinet on Climate Change (Gabinete Nacional de Cambio Climático, or GNCC), a working group composed of members from 17 different ministries that is coordinated by MAyDS and has the task of elaborating the strategies and instruments to implement national climate objectives (Government of Argentina, 2017).

As projected by our modeling framework, future emissions growth in Argentina will largely center in the energy sector. Rapid growth in electricity demand and related power sector emissions, coupled with a relatively ambitious NDC, offer a significant opportunity for renewable energy deployment (Bloomberg New Energy Finance, 2017). Recent developments in energy legislation suggest that Argentina is looking to harness this opportunity. Under Law N° 27.191, passed on 15 October 2015, it has increased earlier targets for the share of renewable energy (other than large hydro) in electricity consumption to 8% by the end of 2018, 12% by 2019, 16% by 2021, 18% by 2023 and 20% by 2025 (Government of Argentina, 2015).

An early system of modest feed-in tariffs adopted in 2006 under Law N° 26.190 (Government of Argentina, 2006) proved relatively ineffective in driving renewable energy investment, and was narrowed to facilities with generating capacity below 30 MW under Law N° 27.191 (Norton Rose Fulbright, 2016). Instead, Argentina has joined many of its neighboring countries by relying on reverse auctions for long-term Power Purchase Agreements (PPAs) to promote the development of renewable energy. As early as 2010, it launched the Renewable Energy Generation Program (Programa de Generación de Energía Eléctrica a partir de Fuentes Renovables, or GENREN) tender program, requiring the state utility (Energía Argentina Sociedad Anónima, or ENARSA) to contract at least 1 GW of renewable energy capacity and sell it to the grid at fixed rates for a period of 15 years. Although this early scheme yielded 1.4 GW in offers and 895 MW in signed contracts, only 128 MW ended up actually being commissioned. Lack of financing due to high perceived sovereign and offtaker risk were cited as the primary reason for this weak outcome (Bloomberg New Energy Finance, 2017).

In execution of Law N° 27.191 and its implementing Decree N° 531/2016, the Ministry of Energy and Mining (Ministerio de Energía y Minería) has elaborated a new renewable energy auctioning program (Plan de Energías Renovables Argentina 2016-2025, or RenovAr) featuring a reverse auction bidding process to contract renewable electricity (GlobalData, 2017). It addresses the shortcomings of the GENREN program by lowering risk and ensuring better financial conditions for bidders. This time, the liquidity of the offtaker of contracted electricity, the Wholesale Electricity Administrator Company (Compañía Administradora del Mercado Mayorista Eléctrico, or CAMMESA), is backed by a newly created Fund for the Development of Renewable Energies (Fondo para el Desarrollo de las Energías Renovables, or FODER). Through this fund, the government serves as trustor and residual beneficiary, the Bank of Investment and Foreign Trade (Banco de Inversion y Comercio Exterior, or BICE) as trustee, and owners of investment projects are the beneficiaries. Itself backed by a World Bank guarantee (Government of Argentina, 2017), FODER protects bidders from offtaker, PPA termination, currency conversion, and certain political risks (Bloomberg New Energy Finance, 2017).

A value-added tax (VAT) rebate, accelerated depreciation rules, and additional income tax and import duty benefits (including a local content rule) further improve the financial viability of renewable energy projects, as do improved transparency requirements about nodal capacities and potential transmission constraints (Cueva and Viña, 2017; Norton Rose Fulbright, 2016). PPAs awarded under RenovAr have a duration of 20 years and are denominated in US$, but paid in Argentinian Pesos using a conversion mechanism and adjusted by an incentive factor to promote fast project completion (Cueva and Viña, 2017). Under Decree N° 531/2016, large consumers, defined as those with average consumption exceeding 300 kW, can opt out of the tendered PPAs and obtain their supply directly from a distributor or from the wholesale market at a price ceiling of $113 per MWh or through self-generation of cogeneration (GlobalData, 2017).

RenovAr has so far resulted in three electric power auctions: Round 1, Round 1.5 and Round 2. Under the first round, it solicited bids for 1,000 MW of renewable energy to the grid, broken down by technology: 600 MW of wind, 300 MW of solar, 65 MW of biomass, 20 MW from small dams, and 15 MW from biogas. It yielded submissions from over 75 companies for 123 projects amounting to 6,346.3 MW in proposals, making the tender six times oversubscribed (Norton Rose Fulbright, 2016). Overall, the three RenovAr bidding rounds have resulted in awards to 147 projects for a combined capacity of 4,466.5 MW (Renewables Now, 2018), evidencing the successful uptake of this instrument as a mechanism to promote renewable energy investment: in 2017, Argentina attracted more investment in one calendar year than in the prior six years combined (Bloomberg New Energy Finance, 2017). With average prices in each auction falling from $59.70 per MWh in Round 1 (July 2016) to $40.40 per MWh in Round 2 (November 2017), however, there have been concerns that developers may be undervaluing assets and bidding below actual project cost, which may compromise their ability to secure financing and make a final investment decision (Goldwyn *et al.*, 2018). Initial delays with the execution of projects awarded so far suggest that these concerns are not unfounded, meriting close scrutiny going forward (Critchley, 2018).

Aside from RenovAr, Argentina has introduced several additional programs to promote renewable energy in power generation and transportation. Renewable electrification of remote rural areas is promoted under the Project on Renewable Energy in Rural Markets (Proyecto de Energías Renovables en Mercados Rurales, or PERMER), which has recently entered a second phase. Meanwhile, Law N° 26.093 of 12 May 2006 and its implementing regulations introduced mandatory fuel blending quota for bioethanol and biodiesel in transportation fuels, and currently mandate a 10% share of biodiesel in diesel fuels and 12% of bioethanol in gasoline (Government of Argentina, 2017).

More generally, Argentina has made important progress in reforming its market for electricity and gas. Already one of the most deregulated electricity markets in Latin America, with around 75% of generation capacity in private ownership, Argentina has also recently liberalized electricity and gas pricing. Following the economic recession and fiscal crisis of 2001, the government had responded to political pressure about the cost of energy by fixing electricity and gas prices, which, over time, prompted a considerable decline in infrastructure investment and threatened the security of supply. Despite abundant domestic resources—both conventional and renewable—Argentina therefore faces a current power deficit. Over considerable resistance, the new government has repealed price subsidies for electricity and gas, bringing these closer to real cost.

On the latter front, Argentina is set to join the small number of Latin American countries which have introduced a carbon price when it implements a carbon tax (impuesto al dioxido de carbono) from 1 January 2019. Adopted on 28 December 2017 as part of a comprehensive tax reform, the carbon tax will be imposed as a percentage of the full tax rate of US$ 10/tCO_2e. For most liquid fuels, the tax will be levied at the full rate, whereas for mineral coal, petroleum, and fuel oil, the tax rate will at a tenth of the full tax rate, increasing annually by 10 percent to reach 100 percent in 2028. Producers, distributors and importers of these fuels are liable for payment of the tax, although certain sectors and uses are partially exempt, such as international aviation and shipping, fuel exports, the share of biofuels in mineral oil, and raw materials used in (petro)chemical processes. Altogether, the tax is expected to impose a carbon price on approximately 20% of Argentina’s emissions (World Bank, 2018: 39).

Going forward, Argentina faces numerous policy challenges as it pursues implementation of its climate pledges. Given initial delays under the landmark RenovAr tendering program, the country has to demonstrate the capabilities of this new incentive framework to ensure reliable deployment of renewable energy sources in electricity generation, with robust enforcement of the penalties for delays or default on the part of project developers. For its part, the government should continue pursuing its tendering process for new transmission infrastructure. In a country where a large share of renewable resources are located in the windswept Patagonia region that is covered by a separate grid (Sistema de Interconexión Patagónico, or SIP), adequate interconnection with the country’s main grid (Sistema Argentino de Interconexión, or SADI) will be key to mitigate any curtailment risk for both renewable and thermal generators.

Abundant shale gas reserves in the Vaca Muerta Formation offer an opportunity to simultaneously address energy security concerns and provide a dispatchable, lower-carbon bridge fuel to balance the growing share of variable renewable sources in electricity generation until battery storage is economically more viable (Goldwyn *et al.*, 2018: 9). Attracting foreign investment through robust legal guarantees, fiscal incentives, and adequate infrastructure is vital to accelerate the pace of natural gas exploration and extraction. Care has to be taken, however, to develop these resources responsibly, addressing environmental impacts such as methane leakage, and considering the longer term evolution of the national and global energy system when locking in investment and associated emissions over significant periods of time.

An important step in this regard is the recent introduction of a carbon tax, which can help correct the central market failure underlying climate change. By signaling a more accurate cost of emissions from the production and consumption of fossil fuels, the carbon price can help investors align their investment strategies with decarbonization pathways. Over time, therefore, Argentina should consider expanding the scope of the carbon price beyond the current sectors and activities to cover the economy at large, and increasing the tax rate to a level more consistent with the estimated social cost of carbon. Together with removal of distorting energy subsidies and continued liberalization of the electricity market, these measures can ensure that Argentina meets its growing energy needs in secure, affordable, and, above all, environmentally sustainable manner.

6.4 Results for Colombia

Modeling Results

- Existing plans for the expansion of non-fossil electricity generation are sufficient to meet Colombia's unconditional emissions reduction target.
- Colombia's conditional emissions pledge can be achieved with moderate additional policies. For example, when non-fossil electricity targets are met using an RPS, the addition of an all-sectors ETS that caps emissions at the level consistent with Colombia's conditional pledge results in a carbon price of \$2.9/ tCO_2e and increases the reduction in GDP from 0.495% to 0.500%.
- However, if the ETS only includes electricity and energy-intensive sectors, the required carbon price is much larger and the GDP costs are much greater. For example, under such an ETS, the carbon price is \$602.5 and the decline in GDP is 1.20%. This is because emissions from electricity and energy-intensive sectors only account for around one-fifth of total emissions, so a large proportional reduction in emissions from these sectors is required to meet a national emissions target.
- Although a RPS to meet non-fossil emission reduction targets lowers the carbon price, it increases the GDP cost of reducing emissions. For example, when meeting Colombia's conditional emission reduction pledge using an all-sectors ETS, removing the RPS increases the carbon price from \$2.9 to \$12.6 and lowers reduction in GDP from 0.50% to 0.04%. This is because the RPS only reduces emissions in the electricity sector by a specific means, while an ETS incents emission reductions wherever and however they are cheapest.
- Increased adoption of digitalization in electricity generation lowers the cost of meeting emission reduction targets. For example, when a RPS and an economy-wide ETS is used to meet Colombia's conditional target, digitalization reduces the reduction in GDP cost from 0.500% to 0.477%.

A summary of results for Colombia is reported in Table 6.6, with additional results in Figures 6.5 (GHG emissions), 6.6 (electricity generation), 6.7 (primary energy), and Table 6.6 (sectoral output changes for selected scenarios).[6] In the BAU scenario, the imposed level of GDP in 2030 is \$690.8 billion (in 2011 dollars), an increase of 105.0% relative to 2011. Total GHG emissions in 2030 are 47.0 $MtCO_2e$, a 39.4% increase relative to 2011. The GHG intensity of GDP, therefore, decreases by 32.0% between 2011 and 2030. Electricity generation and primary energy use in 2030 are, respectively, 100.4 TWh and 45.6 Mtoe.

In the RPS scenario, the mandate for non-fossil electricity reduces GDP by 0.5% relative to BAU. Incentives for non-fossil generation increase electricity from other renewables by 18.3% relative to BAU (from 2.7 TWh to 3.2 TWh). At the same time, additional cost for fossil electricity generators—via the requirement to purchase renewable electricity certificates—decreases generation from gas and coal by, respectively, 74.5% and 86.0% relative to BAU. Overall, relative

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[6] Results displayed in Figures 6.5–6.7 are presented in tables in Appendix E.

to BAU, higher electricity costs/prices due to the RPS reduces total electricity use by 31.3%. Economy-wide emissions (excluding LULUCF) in 2030 are 211.3 $MtCO_2e$, below the level consistent with Colombia's unconditional Paris pledge (214.6) but above this nation's conditional pledge (181.4). Excluding electricity sectors, iron and steel production experiences the largest sectoral decline (6.7%, Table 6.7).

When an economy-wide ETS is included as well as the RPS, as in the CON-ALL scenario, a carbon price of $2.9/$tCO_2e$ is required to reduce 2030 emissions to 181.4 $MtCO_2e$. Under the moderate carbon price, GDP and electricity production are similar to those in the RPS scenario.

When the conditional target is met using an ETS on selected energy and energy-intensive sectors in the CON-SEL scenario, the carbon price increases to $602.5/$tCO_2e$. This is because, in the RPS scenario, emissions from selected sectors account for only 22.2% of total emissions. Consequently, relative to the RPS scenario, a 76.7% decrease in emissions from selected sectors is required to reduce economy-wide emissions by 14.2%. Due to the carbon price, electricity from coal all but shuts down and generation from gas falls by 42.5% relative to the RPS scenario (Figure 6.6). Applying the ETS only to selected sectors also increases the cost of meeting Colombia's conditional emissions target from 0.5% of GDP when the ETS is applied to all sectors (CON-ALL) to 1.2% of GDP.

When Colombia's conditional emission pledge is met using an economy-wide ETS without a RPS (CON-ETS), the carbon price is $12.6/$tCO_2e$. This carbon price is higher than when there is all-sectors ETS and a RPS (CON-ALL, $2.9), as the ETS is required to reduce emissions by 43.9 MCO_2e (225.3 – 181.4) without a RPS but only by 29.9 MCO_2e (211.3 – 181.4) when there is an RPS. Without the RPS, there is more total electricity, more electricity from fossil fuels, and less electricity from other renewables. However, by design, total emissions are the same in both the CON-ALL and CON-ETS scenarios, and there is more abatement by non-electricity sectors when there is not a RPS.

Despite the higher carbon price, the GDP cost of meeting the conditional emissions target without the RPS ($0.3 billion) is lower than when there is a RPS ($3.5 billion). This is because the RPS forces the economy to reduce emissions in a specific sector in a specific way (increasing the share of electricity from non-fossil sources), while an ETS without this regulation incents emissions reductions wherever and however they are cheapest. One way that removing the RPS lowers the cost of reducing emissions is by incenting an increase in gas electricity generation relative to generation from coal (i.e., the share of gas electricity in aggregate generation from coal and gas increases from 50.5% when there is a RPS and an ETS, and is 52.9% when there is only an ETS). This is because the carbon price under an ETS increases the cost per unit of generation more for coal electricity, which has a higher CO_2 intensity, than it does for gas electricity.

The impact of increased digitalization in the electricity sector can be evaluated by comparing results for the CON-ALL-DIG and CON-ALL scenarios. The results indicate that increased digitalization lowers the cost of meeting the emissions constraint from 0.5% of GDP (CON-ALL) to 0.48% (CON-ALL-DIG), and has a small impact on the carbon price.[7] Digitalization also increases total electricity generation from 69.0 to 69.3 TWh, largely due to an increase in generation from other renewables. Overall the results suggest that increased adoption of digitalization could lead to modest reductions in the cost of reducing emissions in Colombia.

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[7] Specifically, the carbon price per tCO_2 decreases from $2.95 in the CON-ALL scenario to $2.89 in the CON-ALL-DIG scenario.

Table 6.6. Colombia: Summary results in 2030

	BAU	RPS	CON-ALL	CON-SEL	CON-EST	CON-ALL-DIG
GDP billion 2011$	690.8	687.4	687.3	682.5	690.5	687.5
GDP % change	-	-0.495%	-0.500%	-1.197%	-0.037%	-0.477%
CO_2 price 2011$/t$CO_2$e	-	-	2.9	602.5	12.6	2.9
GHG emissions MtCO_2e						
Selected sectors	64.4	47.0	43.2	11.0	53.7	43.0
Other sectors	160.8	164.4	138.2	170.4	127.7	138.3
All sectors	225.3	211.3	181.4	181.4	181.4	181.4
Elec. generation TWh	100.4	69.0	69.0	64.4	97.5	69.3
Primary energy Mtoe*	45.6	40.9	40.2	33.9	42.7	40.1

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. Colombia: Output changes in 2030 relative to BAU, 2011$ and %

	RPS		CON-ALL		CON-SEL	
	$, b	%	$, b	%	$, b	%
Crude oil	0.068	0.4%	0.071	0.4%	0.173	1.0%
Refined oil products	-0.120	-1.2%	-0.127	-1.2%	-0.408	-3.9%
Coal extraction	-0.058	-2.0%	-0.071	-2.4%	-0.275	-9.4%
Natural gas extraction & dist.	-0.032	-0.2%	-0.044	-0.2%	-0.133	-0.7%
Coal electricity	-0.659	-86.0%	-0.660	-86.1%	-0.750	-97.9%
Gas electricity	-1.490	-74.5%	-1.490	-74.4%	-1.707	-85.3%
Oil electricity	0.001	6.5%	0.001	6.5%	0.001	6.5%
Hydro electricity	0.000	0.0%	0.000	0.0%	0.000	0.0%
Other renewable electricity	0.054	18.3%	0.054	18.3%	0.054	18.5%
Electricity transmission & distrib.	-0.553	-32.4%	-0.553	-32.4%	-0.640	-37.5%
Agriculture	-0.021	0.0%	-0.034	-0.1%	-0.005	0.0%
Other mining	-0.009	-0.1%	-0.010	-0.1%	0.047	0.5%
Chemical, rubber & plastic prod.	-1.385	-2.8%	-1.424	-2.9%	-5.096	-10.2%
Non-metallic minerals	-0.245	-1.4%	-0.258	-1.5%	-1.506	-8.7%
Iron and steel	-0.822	-6.7%	-0.840	-6.9%	-2.135	-17.5%
Non-ferrous metals	0.926	2.7%	0.942	2.8%	3.083	9.2%
Food processing	-0.254	-0.4%	-0.262	-0.4%	-0.490	-0.7%
Motor vehicles and parts	-0.017	-0.2%	-0.020	-0.2%	-0.037	-0.4%
Other manufacturing	-1.390	-1.5%	-1.414	-1.5%	-1.429	-1.5%
Transportation	0.496	0.7%	0.439	0.6%	0.243	0.3%
Services	-2.952	-0.5%	-2.978	-0.5%	-7.411	-1.1%

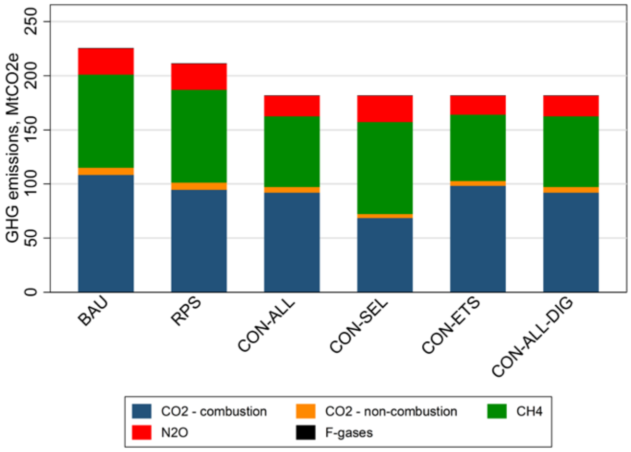

Figure 6.5. Colombia: GHG emissions in 2030, $MtCO_2e$

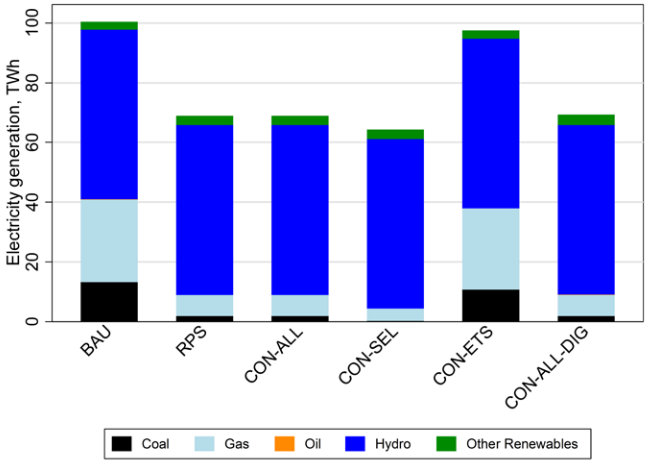

Figure 6.6. Colombia: Electricity generation in 2030, TWh

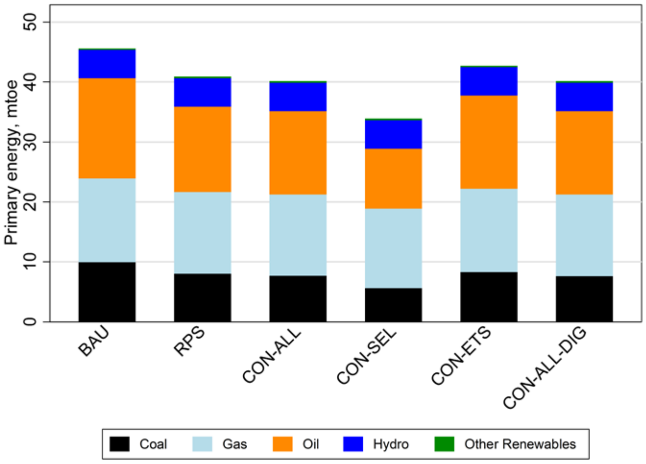

Figure 6.7. Colombia: Primary energy in 2030, Mtoe

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.

6.4.1 Policy Recommendations for Colombia

Main Takeaways

- Colombia is among the most vulnerable countries to climate change in Latin America, affording it a powerful incentive to contribute to global efforts on climate change mitigation. Recent advances include the adoption of a national framework law on climate change, the introduction of a carbon tax, and targeted pursuit of greater diversification in the electricity mix through auctioning.
- Promoting the development of renewable energy is an acknowledged priority for the achievement of Colombia's mitigation objectives. Colombia has considerable renewable energy potential, including biomass, geothermal and solar energy, as well as some of the most favorable conditions for wind energy on the continent.
- Abundant domestic reserves of oil and coal pose a challenge to the meaningful reduction of greenhouse gas emissions in the energy sector, including in transportation. In recent years, increased climate variability, (manifesting in alternating periods of heavy rain and extended droughts) has undermined the reliability of hydroelectric power, prompting increased reliance on fossil-fueled thermal energy.
- Tax benefits for renewable energy sources, an important step in achieving a more diverse electricity mix, have not yet had a significant impact on renewable energy penetration rates given the abundant and low-cost fossil fuel supplies. As renewable energy technologies decline in price, Colombia should phase out fiscal subsidies for all energy sources while extending carbon pricing to coal and natural gas.
- In the near term, targeted auctions for renewable energy can play a useful role in progressing the diversification of the Colombian electricity mix, and preventing further lock-in of long-lived carbon-emitting generation assets.

Colombia has made significant progress in the development of a robust climate and renewable energy policy framework. Recent advances include the adoption of a national framework law on climate change, the introduction of a carbon tax, and targeted pursuit of greater diversification in the electricity mix through auctioning. Still, abundant domestic reserves of oil and coal pose a challenge to the meaningful reduction of greenhouse gas emissions in the energy sector, including in transportation. Intensified land-use in post-conflict areas has also contributed to a concerning rise in emissions from tropical deforestation. To tackle these challenges, Colombia should expand the use of economic instruments such as carbon pricing and ensure a level playing field for all energy sources, continue investing in energy efficiency and clean alternatives for electricity generation and transportation, and carefully manage its ongoing land reform process.

Colombia is among the most vulnerable countries to climate change in Latin America (USAID, 2012), affording it a powerful incentive to contribute to global efforts on climate change mitigation. It has played a constructive role in international climate negotiations (Bustos, 2017), and is one of the regional pioneers in comprehensive and progressive climate policies, such as a national framework law on climate change and a carbon tax. At the same time, sustaining a fragile peace in the formerly war-torn country and ensuring continued economic growth remain central priorities of the national government. Colombia therefore faces pressure to expand the development of its ample oil and coal reserves, solidifying the role of fossil fuels in the domestic energy mix. Together with a regional expansion of agriculture into previously inaccessible areas, resource extraction has contributed to a recent spike in tropical deforestation rates (Weisse and Dow Goldman, 2018), posing a serious challenge to meaningful reduction of domestic emissions. This broader context explains some of the particularities of Colombia's current approach to climate and energy policy.

Institutionally, the National Economic and Social Policy Council (Consejo de Política Económica y Social, CONPES), Colombia's highest authority for national planning, is the body charged with translating climate change components into policy documents (Climate Policy Observer, 2018). On 14 July 2001, it adopted CONPES 3700 on the Institutional Strategy for the Articulation of Policies and Actions in Climate Change, recommending the establishment of a National System of Climate Change (Sistema Nacional de Cambio Climático, SISCLIMA) as the institutional framework for the coordination and promotion of climate policy (Government of Colombia, 2001). Presidential Decree 298 of 24 February 2016 formally established SISCLIMA, which consists of several government entities—including the Ministries of Environment and Sustainable Development, Interior, Finance, Agriculture and Rural Development, Mines and Energy, Transport, Foreign Relations, and National Planning—as well as state, private and civil society entities. It mandate includes "ccordinating, articulating, formulating, monitoring, and evaluating policies, rules, strategies, plans, programs, projects, actions and measures on matters related to climate change adaptation and the mitigation of greenhouse gases" (Government of Colombia, 2016a: Article 1). SISCLIMA is managed by the Intersectoral Comission on Climate Change (Comisión Intersectorial de Cambio Climático, CICC), which is, in turn, operated by the National Planning Department (Departamento Nacional de Planeación, DNP) and the Ministry of Environment and Sustainable Development (Ministerio de Ambiente y Desarrollo Sostenible, MADS), as well as nine Regional Climate Change Nodes (Nodos Regionales de Cambio Climático, NRCC).

In its work, SISCLIMA is guided by several national strategies and planning documents, including the National Climate Change Adaptation Plan (Plan Nacional de Adaptación al Cambio Climático, PNACC), the National REDD+ Strategy (Estrategia Nacional para la Reducción de las Emisiones debidas a la Deforestación y la Degradación Forestal de Colombia, ENREDD+), the Strategy for Fiscal Protection Against Natural Disaster (Estrategia de Protección Financiera ante Desastres), and the Colombian Low Carbon Development Strategy (Estrategia Colombiana de Desarrollo Bajo en Carbono, ECDBC), and the National Climate Finance Strategy (Estrategia Nacional de Financiamiento Climático). Within a year after its formal establishment, SISCLIMA published a National Policy on Climate Change (Política Nacional de Cambio Climático, PNCC), which builds upon all the foregoing strategy and planning documents, and provides guidelines for climate planning and management at the sectoral, local, departmental, regional, and national levels (Government of Colombia, 2017a).

In 2015, the Colombian government launched a project to elaborate a national climate change law, resulting in a draft law being submitted to the national legislature (Congreso de la República de Colombia) on 9 August 2017. The law passed through relevant committees in the Senate (Senado) and the House of Representatives (Cámara de Representantes) in June 2018, and was adopted in a plenary vote followed by signature of the President in late July 2018, allowing its entry into force just before the national elections in early August. Adopted as Law 1931 of 27 July 2018, the new law defines concepts and principles governing national climate change policy, formally enshrines SISCLIMA in federal law and establishes a National Climate Change Council (Consejo Nacional de Cambio Climático) as a permanent organ of the CICC, delineates the national system on climate change information and establishes a national greenhouse gas registry (Registro Nacional de Reducción de las Emisiones de Gases de Efecto Invernadero, RENARE), and sets out economic instruments to address climate change, including a National Program of Tradable Greenhouse Gas Emission Quotas (Programa Nacional de Cupos Transables de Emisión de Gases de Efecto Invernadero, PNCTE) (Government of Colombia, 2018a).

Colombia already has been gaining experience with economic instruments to address climate change. Law 1819 of 2016 introduced a carbon tax on the sales and imports of fossil fuels, including all liquid petroleum derivatives and natural gas for industrial uses, but exempting coal and natural gas used for electricity generation as well as exported fuels (Government of Colombia, 2016b: Part IX, Articles 221 et sqq.) From 1 January 2017, these fuels have been taxed based on their carbon content at a tax rate of approximately \$5 USD/tCO$_2$, increasing annually by the rate of inflation plus one percentage point until the price reaches approximately US\$ 10/tCO$_2$e (IETA, 2018). Decree 926 of 2017 added an option for regulated entities to reduce their tax liability by becoming certified as "carbon neutral" through use of eligible offset credits (Government of Colombia, 2017b).[8] In the first semester of 2017, approximately 2 MtCO$_2$ of offsets were surrendered to lower the tax liability of covered entities (ICAP, 2018). Revenue collection and administration is conferred on the National Directorate of Taxes of Colombia (Dirección de Impuestos y Aduanas Nacionales, DIAN) is in charge of the administration and revenue collection, whereas the Ministry of the Environment and Sustainable Development oversees the emissions reporting as well as the accredited verification entities. Revenue from the tax—estimated at approximately US\$ 220 million per year—flows into a fund for environmental sustainability and sustainable rural development in former conflict zones (Fondo para una Colombia Sostenible).

In the area of energy, Colombia—which already draws around two thirds of its electricity generation from hydroelectric sources—is favored by considerable renewable energy potential, including biomass, geothermal and solar energy, as well as some of the most favorable conditions for wind energy on the continent (Norton Rose Fulbright, 2016: 20). An abundance of affordable domestic fossil fuel resources, including the largest known deposits of coal in South America, has however dampened uptake of alternative energy so far. Promoting the development of renewable energy is therefore an acknowledged priority for the achievement of Colombia's mitigation objectives. Another factor has added urgency to diversification of the country's energy supply: in recent years, increased climate variability, manifesting itself in alternating periods of heavy rain and extended droughts, has undermined the reliability of hydroelectric power, contributing to an energy crisis in 2016. To date, this has prompted growing reliance on fossil-fueled thermal energy (Oxford Business Group, 2017).

Institutionally, energy falls under the jurisdiction of the Ministry of Mines and Energy (Ministerio de Minas y Energía, MME), which is responsible for policymaking and supervision of energy markets (GlobalData, 2017: 78). An Energy and Mining Planning Unit (Unidad de Planeación Minero Energética, UPME) assists the ministry with advice and support in planning and implementation, and the Energy and Gas Regulation Commission (Comisión de Regulación de Energía y Gas, CREG) regulates trading, transmission, distribution, generation, and interconnection. Colombia's electricity market is governed by Laws 142 and 143 of 1994 (Government of Colombia, 1994a and 1994b), which divide the power market into four activities: generation, transmission, distribution, and retail. Colombia has been a pioneer in electricity market deregulation, implementing a wholesale power market in 1995 and—uniquely for Latin America—extending competition to the retail level (IRENA, 2016: 35). Power can either be traded through the spot market or through bilateral contracts (GlobalData 2017: 78).

On renewable energy, Colombia adopted a Program for the Rational and Efficient Use of Energy and Other Forms of Non-Conventional Energy (Programa de Uso Racional y Eficiente de la En-

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[8] Eligible offset projects under this program include domestic projects implemented after 1 January 2010 under one of the following methodologies: Clean Development Mechanism (CDM); certification programs or carbon standards that have been either publicly consulted and verified by a third party appropriately accredited or issued by the UNFCCC, or recognized by the national government, or that meet the requirements for registration in the REDD+ registry. Voluntary carbon offsets are also eligible if they have been verified according to the methodology established by ISO 14064-2:2006 or another suitable standard, in compliance with Decree 926.

ergía y demás Formas de Energía No Convencionales, PROURE) in 2010, committing to indicative targets and timetables for renewable energy deployment. Specifially, it aims to achieve a share of renewable (other than large hydroelectric) generation of 6.5% in on-grid and 30% in off-grid generation by 2020 (Government of Colombia, 2010: Article 7). In addition, Colombia enforces blending mandates of 10% biodiesel in conventional diesel and 10% ethanol in conventional gasoline. On a more programmatic level, Law 1665 in 2013 endorsed the statute of the International Renewable Energy Agency (IRENA) and its broader objectives (Government of Colombia, 2013).

One year later, in 2014, Colombia adopted Law 1715 to promote the integration of renewable energy, including forestry and agricultural biomass, solid waste, reforestation activities, solar, wave, wind, small hydropower, and geothermal energy, into the electric grid, and to promote self-consumption of electricity generated in off-grid areas (Government of Colombia, 2014). It mandates the harmonization of environmental requirements, the development of environmental impact assessment procedures for renewable energy projects, and the establishment of a rapid assessment cycle for renewable energy projects (IEA *et al.*, 2018). Under this law and subsequent decrees, small-scale generators under 1 MW of generating capacity can benefit from simplified procedures and net metering. Additionally, investors in renewable energy equipment can claim several tax benefits, including:

- an income tax deduction of 50% of investment value for up to 50% of taxable income for up to 5 years;
- an exemption from the Value-Added Tax (VAT), which currently stands at 19%, for renewable energy equipment and services;
- an import duty exemption for renewable energy equipment not produced locally; and
- accelerated depreciation of up to 20% per year for renewable energy investments (Bloomberg New Energy Finance, 2017; IEA *et al.*, 2018).

Additionally, Law 1715 contains provisions to further develop, execute, and finance PROURE, and to establish best practices for public sector energy efficiency, targets for energy-efficient government buildings, and incentives for the development and implementation of demand-response infrastructure (GlobalData, 2017: 81).

Several public funds provide financial support for renewable energy projects, including a Fund for Non-Conventional Energies and Efficient Energy Management (Fondo de Energías No Convencionales y Gestión Eficiente de la Energía, FENOGE) created by Law 1715 (Government of Colombia, 2014: Article 10), a Rural Electrification Fund (Fondo de Apoyo Financiero para la Energización de las Zonas Rurales Interconectadas, FAER) approved in 2003 and a Fund for the Electrification of Non-interconnected Zones (Financiero para la Energización de las Zonas no Interconectadas, FAZNI) established in 2000. Each of these funds is financed by allocation of a small surcharge on wholesale energy prices.

Legal mandates and financial incentives are also in place to promote energy efficiency. Law 697 on the Rational and Efficient Use of Energy and the Use of Non-Conventional Energy Sources of (Government of Colombia, 2001), in particular, along with several subsequent decrees, set out general principles on energy efficiency, sectoral energy savings targets, and technology mandates for specific issues such as efficient lighting (GlobalData 2017: 79). In 2016, UPME published a roadmap for directing smart grid investment through 2030, focusing on four areas: smart metering roll-out, distribution automation, distributed energy integration and electric vehicle adoption. It anticipates that, by 2030, the planned investment will reduce outages from an average of 29.5 hours per year per Colombian household to 5.4 hours (Bloomberg New Energy Finance, 2017).

Overall, Colombia has elaborated a comprehensive framework of laws and regulations for climate change mitigation and the promotion of renewable energy. Institutionally, SISCLIMA ensures a degree of coordination across government agencies, and progress is also being made in streamlining administrative actions at the national and regional level. With competition at the wholesale and retail level, the Colombian electricity market is among the most deregulated in Latin America. Together, this provides a solid basis for further advances in domestic climate policy and expanded use of Colombia's abundant low-carbon energy resources.

There is room for further improvement, however. While Colombia's pioneering role in introducing a price on carbon marks and important step to internalize the environmental cost of fossil fuel combustion in consumer behavior, it exempts coal and gas used in electricity generation. The latter stand to become a rapidly growing source of greenhouse gas emissions as the country grapples with climate-induced volatility in hydroelectric generation, and is forced to rely on dispatchable thermal generation to balance unanticipated shortfalls. Tax benefits for renewable energy sources are an important step in achieving a more diverse electricity mix, but have not yet had a significant impact on renewable energy penetration rates given abundant and low-cost fossil fuel supplies. As renewable energy technologies decline further in price, Colombia should consider reducing and eventually phasing out fiscal subsidies for all energy sources while extending carbon pricing—potentially through an emissions trading system, as allowed under the recently adopted Law 1931—to coal and natural gas, and ensuring price levels that better reflect the social cost of carbon emissions. This can achieve a level playing field across energy sources and better complement the aim of a competitive, deregulated electricity market.

In the near term, targeted auctions for renewable energy can play a useful role in progressing the diversification of the Colombian electricity mix, and preventing further lock-in of long-lived carbon-emitting generation assets. A government decree issued in March 2018 to "strengthen the resilience of the electricity generation matrix to events of variability and climate change through risk diversification" (Government of Colombia, 2018b: Article Artículo 2.2.3.8.7.3 (i)) and a resolution issued in August 2018 by MME establish guidelines for long-term contracting of electricity generation through auctions, including eligibility conditions and a system of guarantees (Government of Colombia, 2018c: Articles 40 et sqq.) A first auction for 3,443,000 MWh of generation—or roughly 4.35% of projected electricity demand in 2022—has been scheduled for January 2019 (Government of Colombia, 2018d). Although all electricity sources are eligible, low- and zero-carbon technologies are heavily favored in the calculation of the award criteria (Government of Colombia, 2018c: Articles 34 and 38). Aside from renewable energy sources, this can also improve the prospects for development of the country's significant, but largely untapped, natural gas reserves located in the Northern Coast and Barranca regions, and in the La Guajira department in northern Colombia.

The relatively modest carbon tax on fuel will likely prove insufficient to meaningfully curb emissions in the transportation sector, calling for consideration of additional measures—including targeted investment in public transportation and electric vehicle infrastructure—or an accelerated increase of carbon tax rates. Beyond the energy sector, improved land use planning and the shape of future land reform will be critical to manage a concerning trend of increased deforestation. Similarly, mining and extraction activities have the potential to significantly increase Colombian greenhouse gas emissions, requiring careful balancing of economic and environmental interests. Finally, to better understand the country's emissions profile, the elaboration of a national greenhouse gas emissions registry as envisioned in Law 1931 is an important step that merits allocation of required administrative and financial resources.

6.5 Comparison of results for Argentina and Colombia

Argentina and Colombia have specified plans to increase generation from non-fossil sources. The analyses indicate that these plans—combined with BAU efficiency improvements—will be sufficient to meet each nation's unconditional emissions reduction pledge. More stringent conditional emission pledges can be achieved with moderate additional policies. For example, in addition to an RPS to meet non-fossil electricity goals, using an all-sectors ETS results in carbon prices per tCO_2e of $6.8 and $2.9 in, respectively, Argentina and Colombia. The cost of the additional policies, however, can be quite high if these policies only target electricity and energy-intensive sectors. This is because, in both nations, emissions in electricity and energy-intensive sectors account for around one-fifth of total emissions, so large reductions in emissions from these sectors are needed to meet economy-wide emission targets. Another common finding is that, when there is an all-sectors ETS, removing the RPS to meet non-fossil electricity generation targets lowers the cost of reducing emissions, even though it increases the carbon price.

Turning to differences in results for the two countries, in Colombia replacing coal electricity was a meaningful abatement option is some policy scenarios. This was not the case in Argentina, as coal electricity accounts for a small proportion of total electricity generation in the 2030 BAU.

Lessons Learned

Targets for renewable electricity (including planned increases in electricity from nuclear and hydro) combined with business as usual efficiency improvements are sufficient to meet unconditional pledges in Argentina and Colombia. In both countries, more-stringent conditional emission targets can be achieved with moderate additional policies. For example, an economy-wide ETS that caps emissions at the conditional level resulted in carbon prices in Argentina and Colombia of, respectively, $6.8 and $2.9 per tCO_2e.

However, when the ETS only covered electricity and energy-intensive sectors, the carbon prices were much higher ($419.6 and $602.5 in, respectively, Argentina and Colombia) and the GDP costs were greater. The key insight here 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.

The simulations also showed that adding an RPS to an all-sectors ETS increased the cost of meeting emission targets (even though it decreased the carbon price). This is because the RPS reduced emissions in only the electricity sector and it did so in a specified way (increasing the share of electricity from non-fossil sources). Notably an RPS does not penalize coal electricity for its higher CO_2 intensity relative to gas power, so it does not incent a shift from coal to gas generation. In contrast, an economy-wide ETS reduces emissions wherever and however emissions reduction are cheapest. These findings illustrate the well-established concept that regulations (e.g., a RPS) are more costly than market-based measures (e.g., a carbon price evolving under an ETS).

Simulations evaluating the impact of digitalization indicated that greater adoption of digital technologies can reduce the cost of meeting emission targets while at the same time increasing electricity generation.

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 LAM nations to avoid costly pathways and reap the full benefits of a robust climate policy portfolio.

As Section 5 shows, LAM 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 LAM 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 LAM 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.

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.

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).

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.

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 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 (NHTSA) 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

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[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 ('backloading') 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.

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Appendix A. Summary of LAM countries' pledges

Official Pledges			Country Estimates 2030		MIT Estimates			
Stringency	**Type**	**Description**	**BAU Emissions (MtCO$_2$e)**	**Target Emissions (MtCO$_2$e)**	**Policy Emissions (MtCO$_2$e)**	**2030 BAU (MtCO$_2$e)**	**Absolute Reduction (MtCO$_2$e)**	**% Reduction in 2030 (Rel. to BAU)**
ARGENTINA								
Unconditional	Total GHG emissions (cap)	421 MtCO$_2$e economy-wide in 2030	592	483	459	483	-24	-5%
Conditional	Total GHG emissions (cap)	306 MtCO$_2$e economy-wide in 2030	592	369	459	369	90	20%
BRAZIL								
Unconditional	Total GHG emissions	37% reduction in 2025 relative to 2005			1,468	1,692	-224	-15%
Conditional	Total GHG emissions	None			1,468	1,692	-224	-15%
CHILE								
Unconditional	Total GHG emissions	None			128	136	-8	-6%
	Emission intensity of GDP	30% reduction in 2030 relative to 2007						
	LULUCF	Recovery of 100,000 hectares of forest land						
	LULUCF	Reforestation of 100,000 hectares land						
Conditional	Total GHG emissions	None			128	126	2	2%
	Emission intensity of GDP	35%–45% reduction in 2030 relative to 2007						
	LULUCF	Recovery of 100,000 hectares of forest land						
	LULUCF	Reforestation of 100,000 hectares land						
COLOMBIA								
Unconditional	Total GHG emissions	20% reduction in 2030 relative to BAU			183	169	14	8%
Conditional	Total emissions	30% reduction in 2030 relative to BAU			183	144	40	22%
ECUADOR								
Unconditional	Total GHG emissions	None			85	69	16	19%
	Energy sector emissions	20.4–25% reduction in 2025 relative to BAU						
Conditional	Total GHG emissions	None			85	54	31	36%
	Energy sector emissions	37.5–45.8% reduction in 2025 relative to BAU						
MEXICO								
Unconditional	Total GHG emissions	22% reduction in 2030 relative to BAU			789	757	32	4%
	Black Carbon emissions	51% reduction in 2030 relative to BAU						
Conditional	Total GHG emissions	36% reduction in 2030 relative to BAU			789	628	161	20%
	Black Carbon emissions	70% reduction in 2030 relative to BAU						
PANAMA								
Unconditional	Total GHG emissions	None			19	23	-4	-23%
Conditional	Total GHG emissions	None			19	23	-4	-20%
	Renewables	15% increase in renewables' share of generation in 2025 relative to 2014						
	Renewables	30% increase in renewables' share of generation in 2050 relative to 2014						
	Forestry	10% increase in CO$_2$ sequestration in 2050 relative to BAU						
PERU								
Unconditional	Total GHG emissions	20% reduction in 2030 relative to BAU	139.3 (298.3 w/ LULUCF)	--	137	139	-2	-1%

Official Pledges			Country Estimates 2030		MIT Estimates			
Stringency	**Type**	**Description**	**BAU Emissions ($MtCO_2e$)**	**Target Emissions ($MtCO_2e$)**	**Policy Emissions ($MtCO_2e$)**	**2030 BAU ($MtCO_2e$)**	**Absolute Reduction ($MtCO_2e$)**	**% Reduction in 2030 (Rel. to BAU)**
Conditional	Total GHG emissions	30% reduction in 2030 relative to BAU	139.3 (298.3 w/ LULUCF)	--	137	133	4	3%
URUGUAY								
Unconditional	Total GHG emissions	None			53	54	0	-1%
	Emission intensity of GDP (BY GAS)	Reductions in 2030 relative to 2007: 24% CO_2, 57% CH_4, 48% N_2O						
	Emission intensity of beef production (BY GAS)	Reductions in emissions per kg of beef cattle (live weight) in 2030 relative to 2007: 32% CH_4, 34% N_2O						
	LULUCF - Forests	Maintenance of 100% of native forest area (849,960 ha), at least 100% of managed forest area (763,070 ha), and 100% of shelter forest area (77,790 ha) of year 2012						
	LULUCF - Soil Organic Carbon (SOC)	Avoid CO_2 emissions from SOC in 10% of grasslands (1,000,000 ha), 50% of peatlands in year 2016 (4,183 ha), and 75% of cropland under Plans of Soil Use and Management of year 2016 (1,147,000 ha); CO_2 sequestration in remaining 25% of cropland (383,000 ha)						
Conditional	Total GHG emissions	None			53	51	3	5%
	Emission intensity of GDP (BY GAS)	Reductions in emission intensity of GDP in 2030 relative to 2007: 29% CO_2, 59% CH_4, 52% N_2O						
	Emission intensity of beef production (BY GAS)	Reductions in emissions per kg of beef cattle (live weight) in 2030 relative to 2007: 37% CH_4, 38% N_2O						
	LULUCF - Forests	5% increase in of native forest area (892,458 ha), at least 100% of managed forest area (763,070 ha), and 25% of shelter forest area (97,338 ha) of year 2012						
	LULUCF - Soil Organic Carbon (SOC)	Avoid CO_2 emissions from SOC in 30% of grasslands (3,000,000 ha), 100% of peatlands in year 2016 (8,366 ha), and 75% of cropland under Plans of Soil Use and Management of year 2016 (1,147,000 ha); CO_2 sequestration in remaining 25% of cropland (383,000 ha)						
VENEZUELA								
Unconditional	Total GHG emissions	None			309	366	-57	-18%
Conditional	Total GHG emissions	20% reduction in 2030 relative to BAU			309	293	16	5%

Appendix B. Methodology

Energy Supply

1. **Estimate Baseline scenario energy mix**
    a. Project GDP MER
        i. Use historical and projected GDP data (2000-2022) from IMF (2017) to project GDP out to 2030.
    b. Project total primary energy supply (TPES)
        i. Use historical TPES of GDP data (2000-2015) to project energy intensity out to 2030
        ii. Multiply energy intensity and GDP to estimate total TPES out to 2030. Determine future TPES by fuel assuming the same fuel shares as in 2015.
    c. Use TPES projections to estimate electricity generation
        i. Calculate the ratio of generation to TPES by fuel (GWh/ktoe) in 2015. Project forward this ratio to 2030 assuming a 0.1% annual increase in efficiency for natural gas.
        ii. 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).
2. **Estimate Policy scenario energy mix**
    a. Incorporate fuel-specific generation and energy supply plans into a Policy scenario energy mix for 2030. Country-specific plans are described in Section 5.

GHG Emissions

1. **Estimate energy sector CO_2 emissions in 2030 in the Baseline and Policy scenarios**
    a. Apply carbon coefficients to projected energy supply of coal, oil, and natural gas (0.00396 $MtCO_2$/ktoe coal, 0.00307 $MtCO_2$/ktoe oil, 0.00235 $MtCO_2$/ktoe natural gas) to calculate combustion CO_2 emissions.
2. **Project energy sector CH_4 and N_2O emissions out to 2030**
    a. Project energy sector CH_4 and N_2O from 2014 (IEA 2017c) out to 2030 using the average annual growth rate of natural gas production according to the 2016 IEA Energy Outlook (3.7% in Argentina, 4.3% in Brazil, and 1.2% in other LAM countries)
3. **Project non-energy sector emissions out to 2030**
    a. Project non-energy sector CH_4 and N_2O from 2014 (IEA 2017c) out to 2030 using the modeled GDP growth rate based on IMF (2017)
    b. Project non-energy sector CO_2, HFC, PFC, and SF_6 from 2014 (IEA 2017c) out to 2030 using the modeled population growth rate based on UN (2017).
4. **Note that LULUCF emissions are excluded from MIT estimates**

NDC Emission Targets

1. **Determine country-level NDC targets.**
    a. Apply conditional and unconditional goals to Baseline scenario emissions, emission intensity, or energy intensity projections.
    b. Calculate the emissions gap as the difference between the estimated NDC target level and Policy scenario emissions in 2030.
    c. Modeled targets are summarized in Table 2.1 while complete official pledges are listed for reference in Appendix A.
2. **Determine regional NDC targets.**
    a. Aggregate country-level conditional and unconditional targets to the LAM region.

b. In aggregating unconditional targets, assume Baseline scenario emissions for countries without an unconditional target. In aggregating conditional targets, assume the unconditionally targeted emissions for countries without a conditional target.

c. For the emissions gap, record no contribution to regional, targeted reductions from countries with 2030 NDC targets greater than Policy scenario emission (i.e., a negative emissions gap).

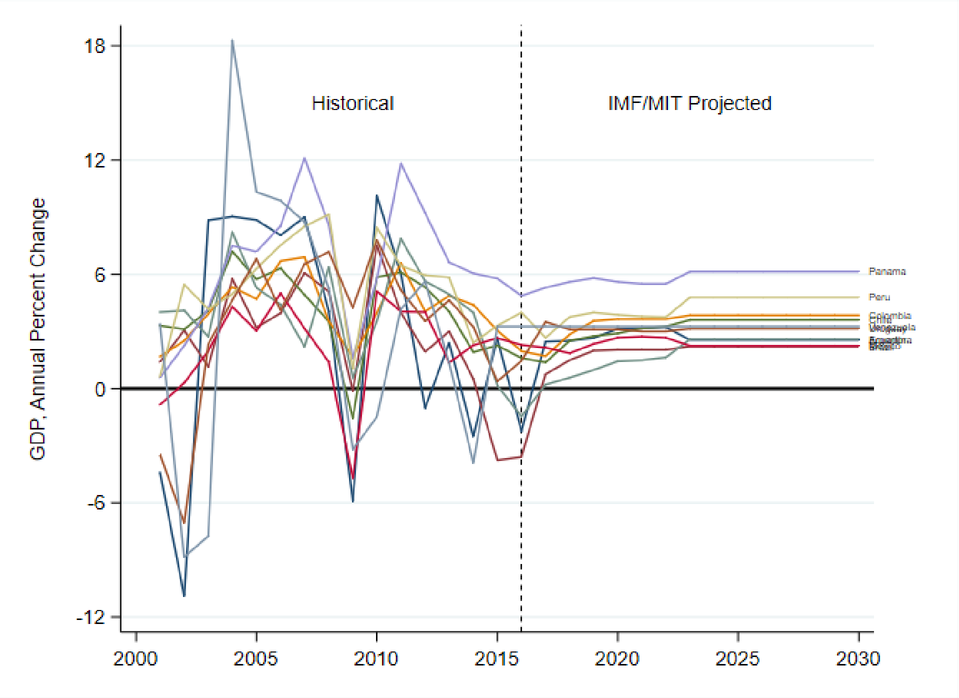

Figure B.1. GDP historic real growth rates (2000-2016) and our long-term growth rate assumptions (2016-2030) for the LAM region

Appendix C. Energy and emission intensity

Argentina

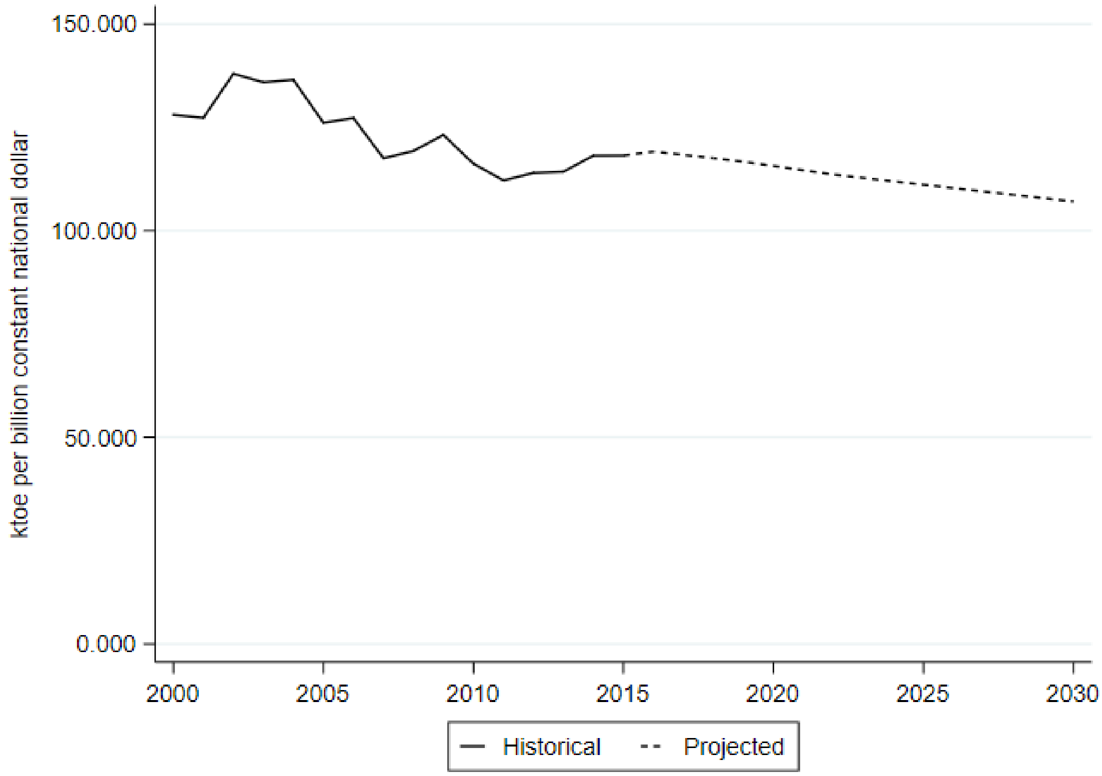

Figure C.1. Energy intensity of GDP in Argentina

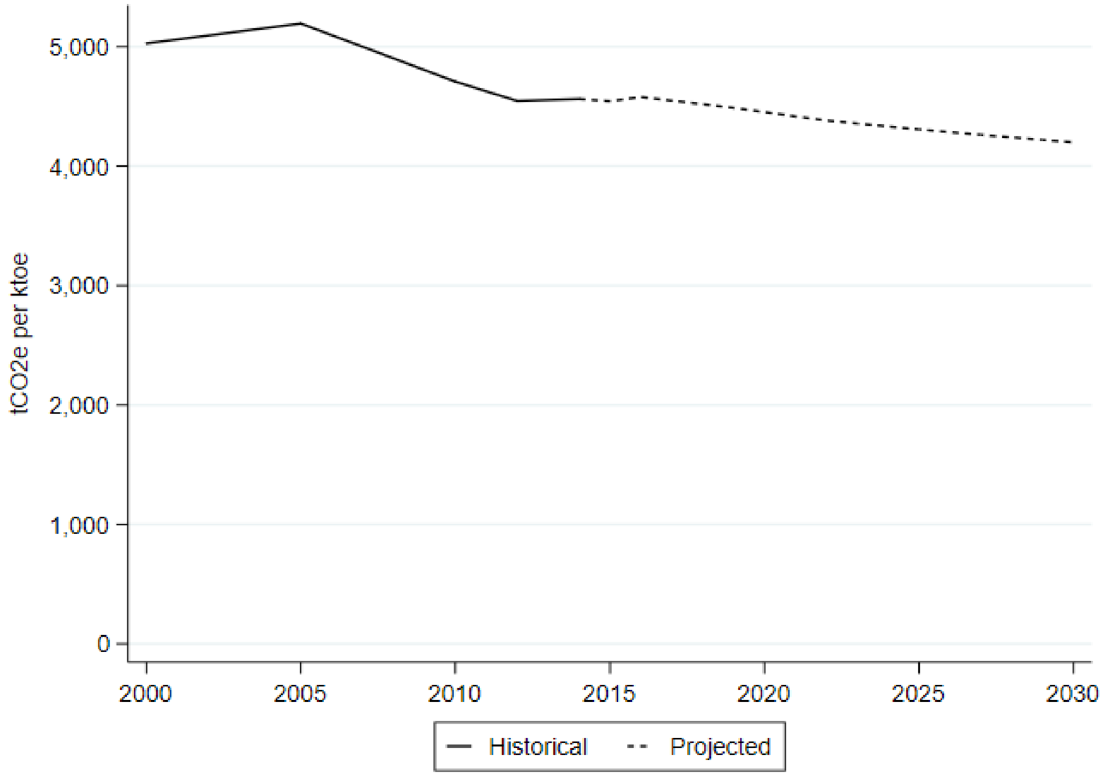

Figure C.2. Emission intensity of TPES in Argentina

Brazil

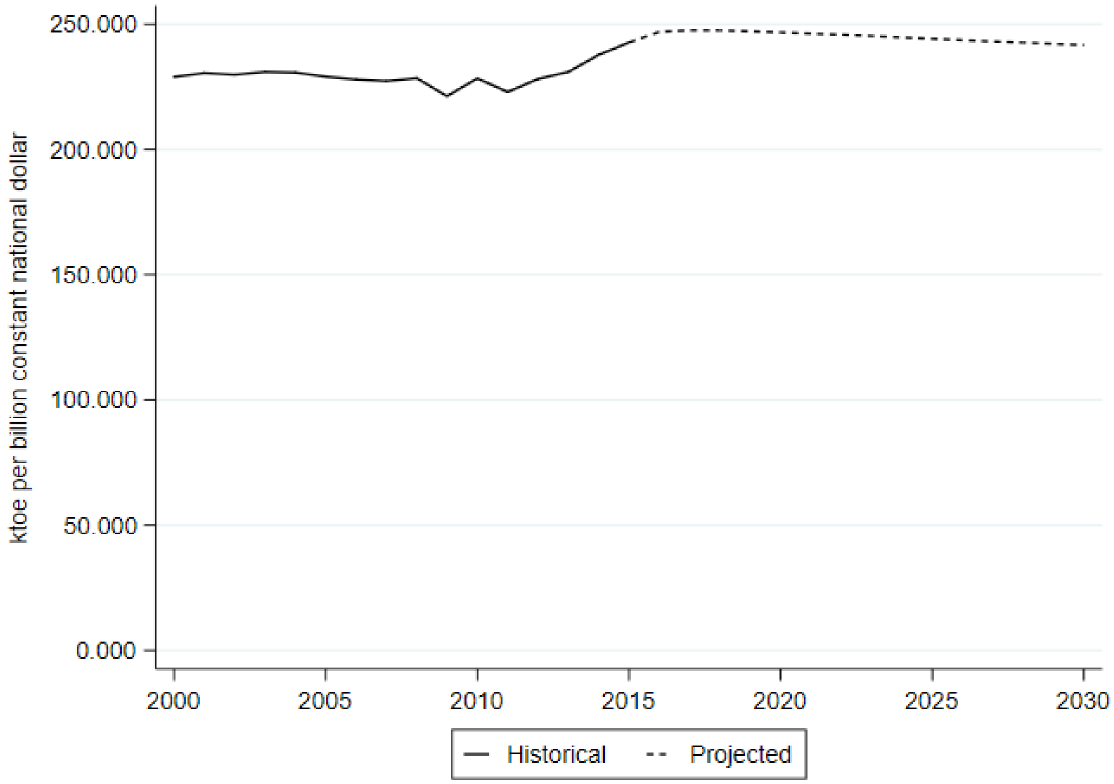

Figure C.3. Energy intensity of GDP in Brazil

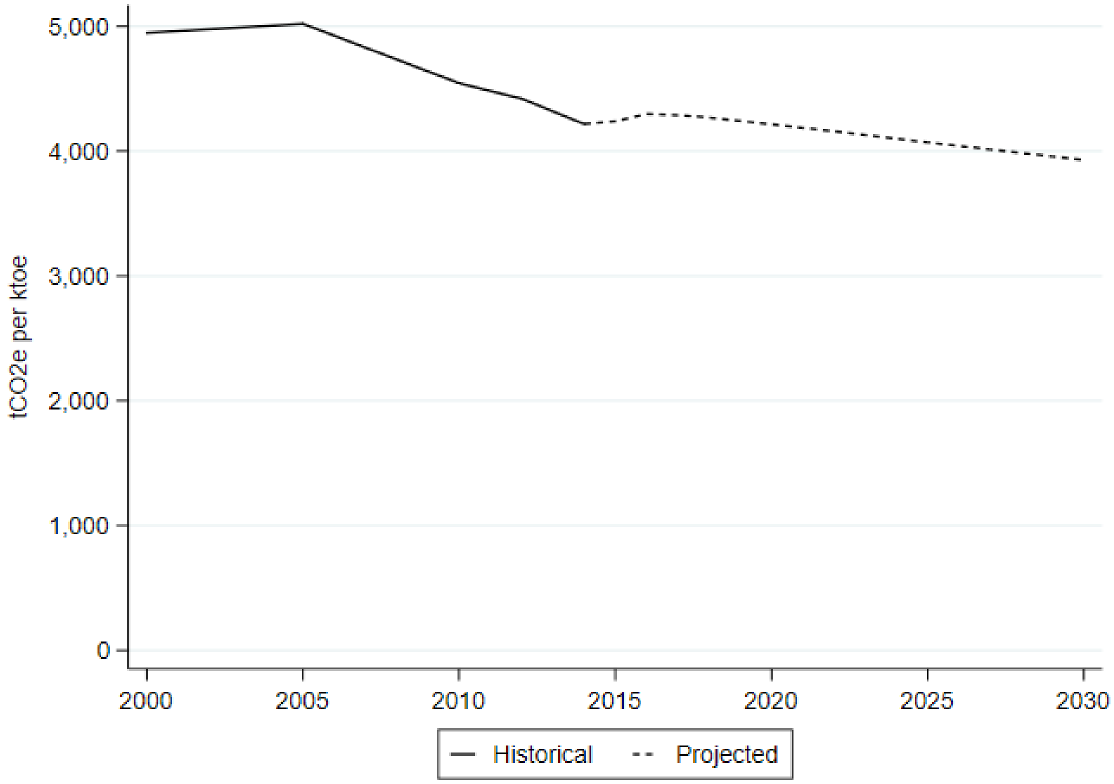

Figure C.4. Emission intensity of TPES in Brazil

Chile

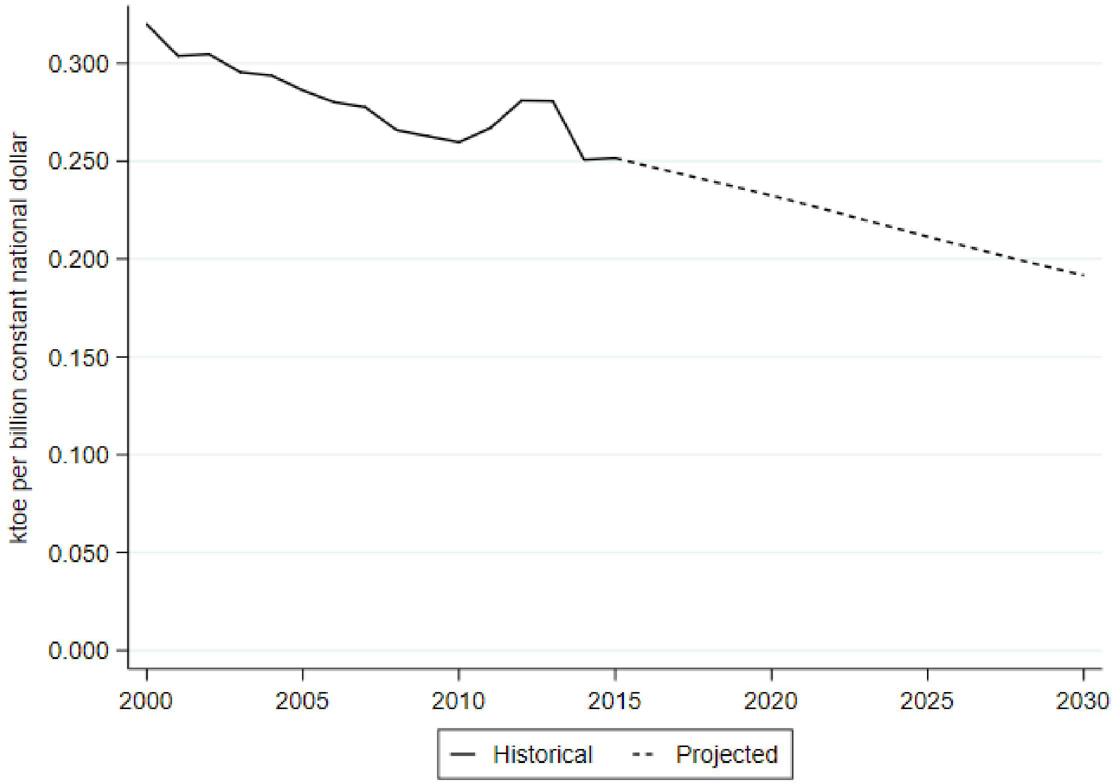

Figure C.5. Energy intensity of GDP in Chile

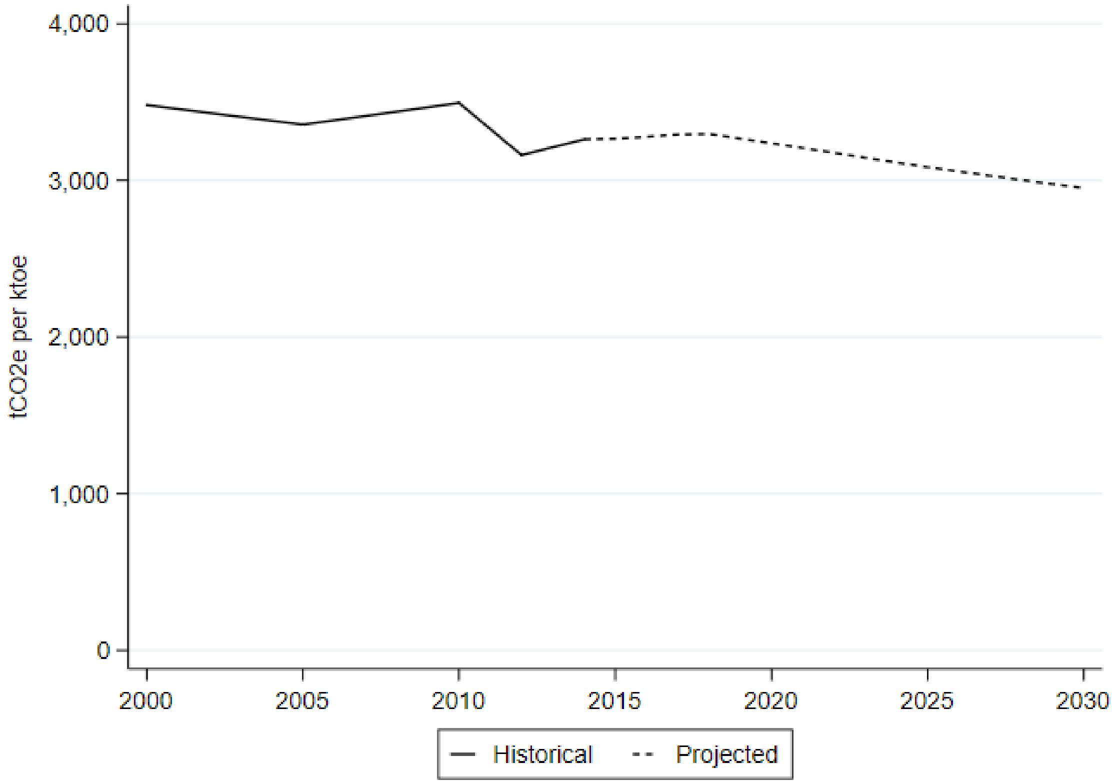

Figure C.6. Emission intensity of TPES in Chile

Colombia

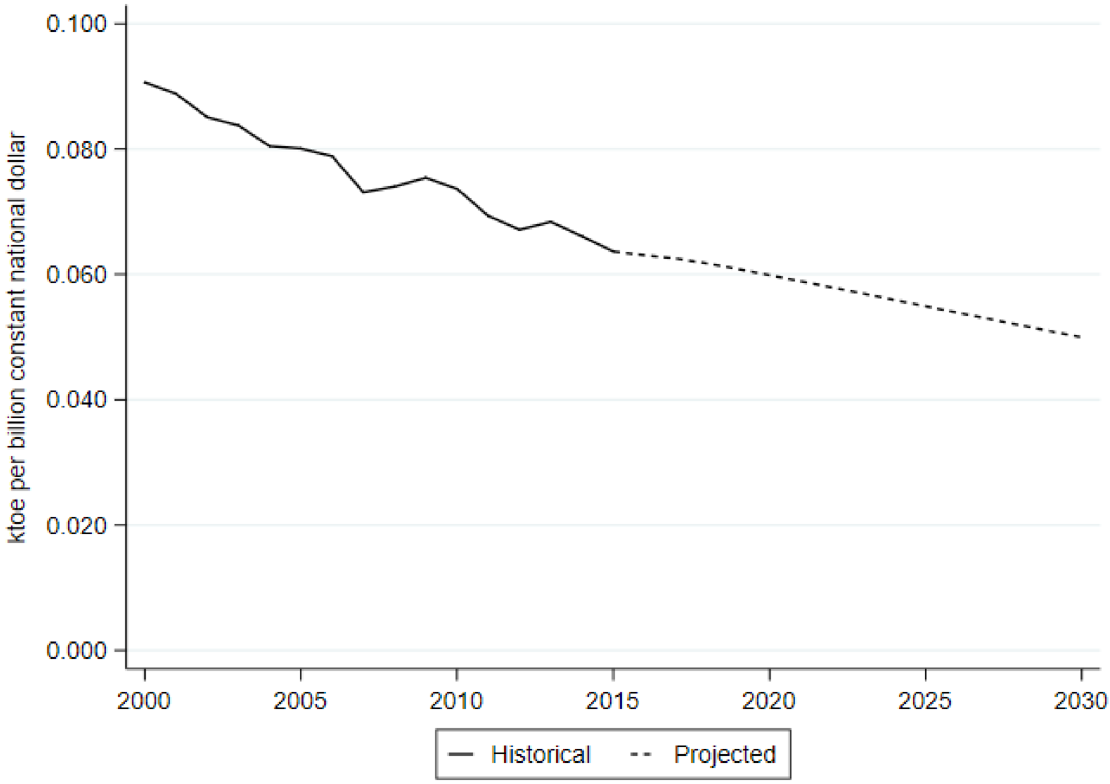

Figure C.7 Energy intensity of GDP in Colombia

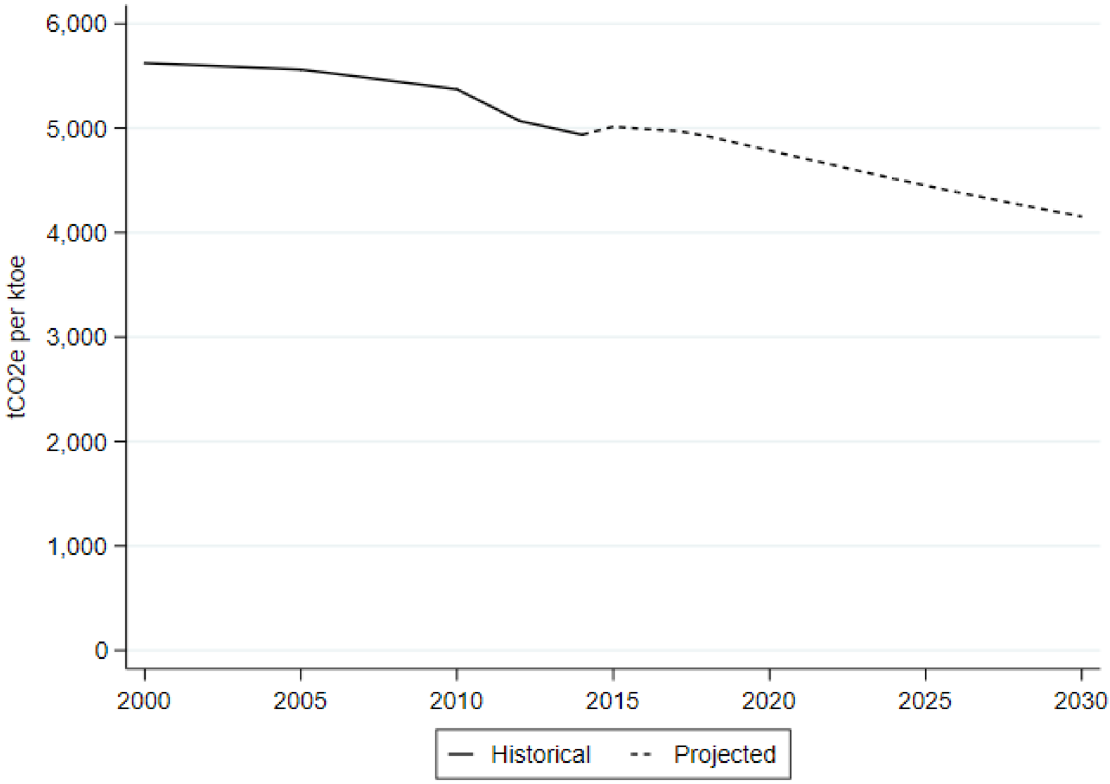

Figure C.8. Emission intensity of TPES in Colombia

Ecuador

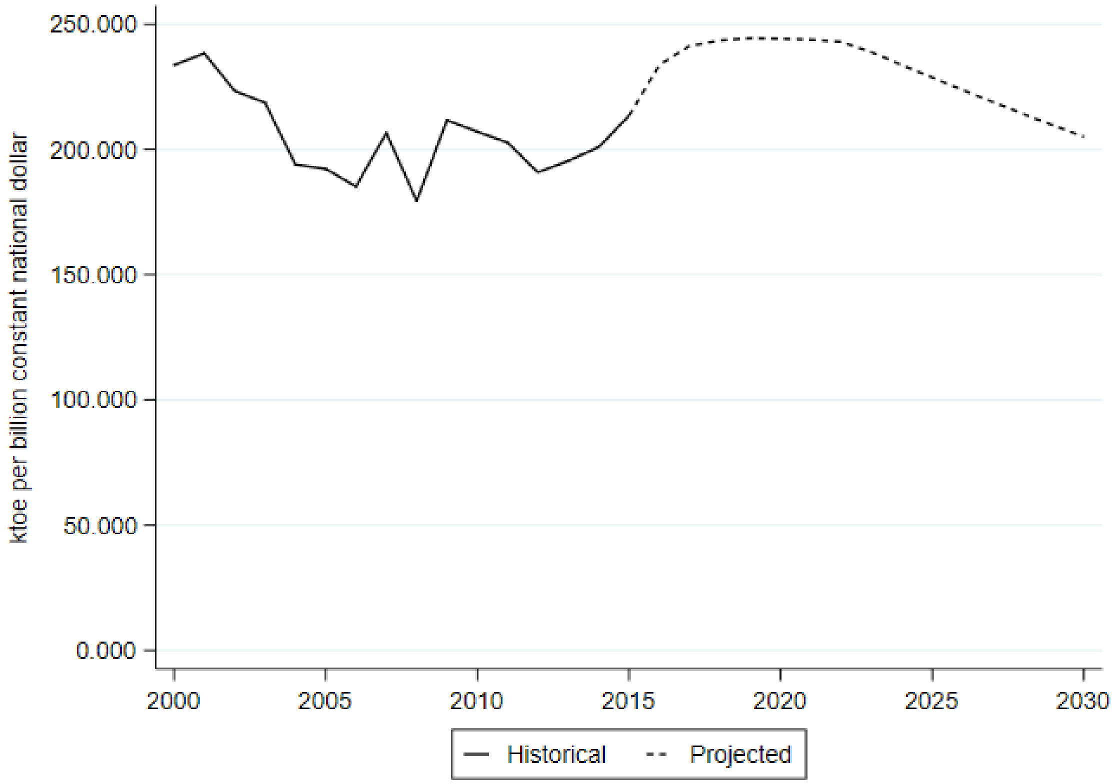

Figure C.9. Energy intensity of GDP in Ecuador

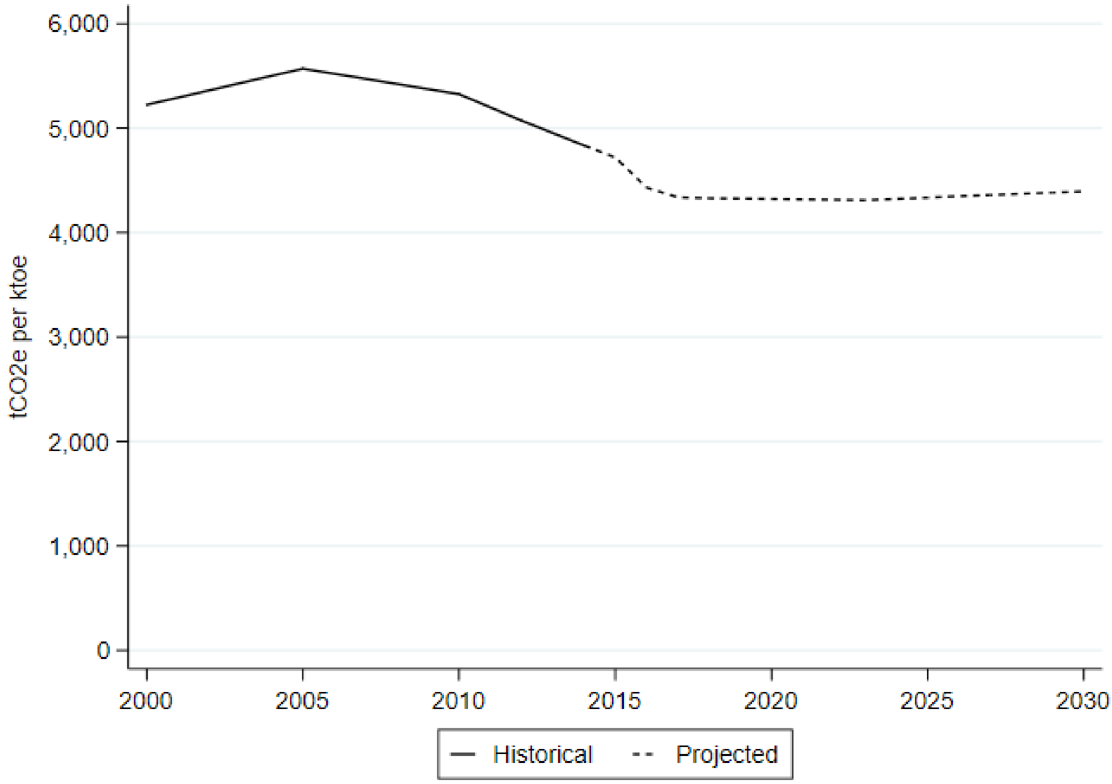

Figure C.10. Emission intensity of TPES in Ecuador

Mexico

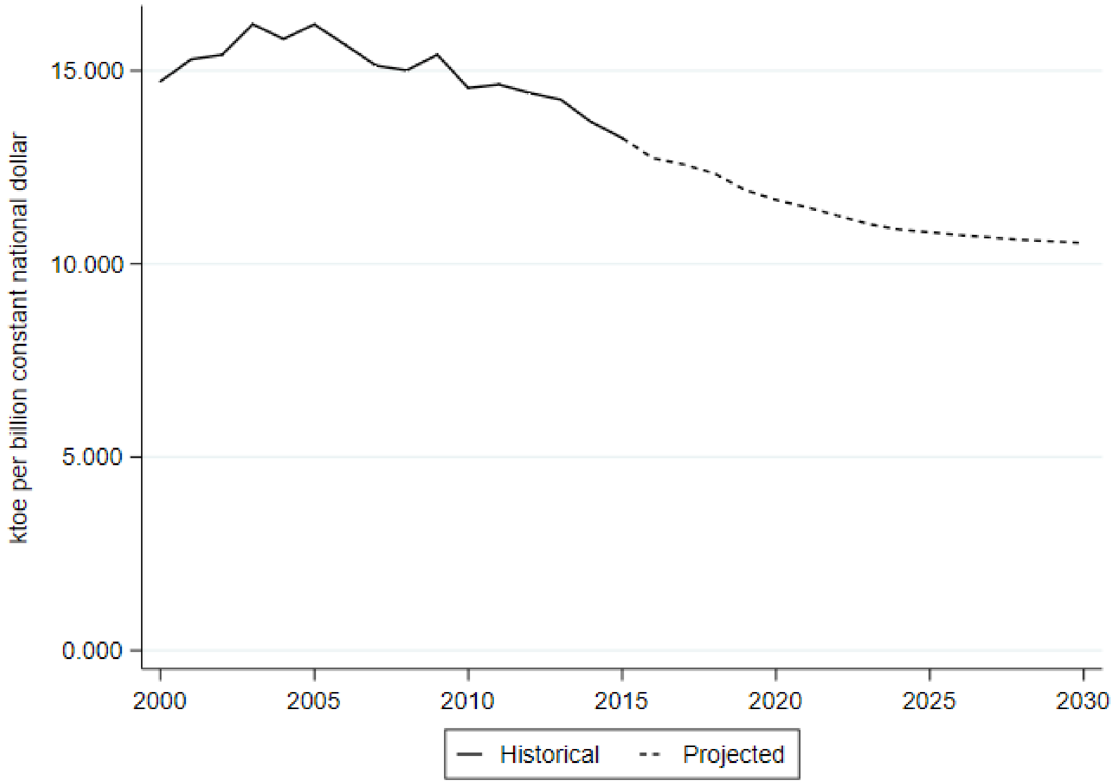

Figure C.11. Energy intensity of GDP in Mexico

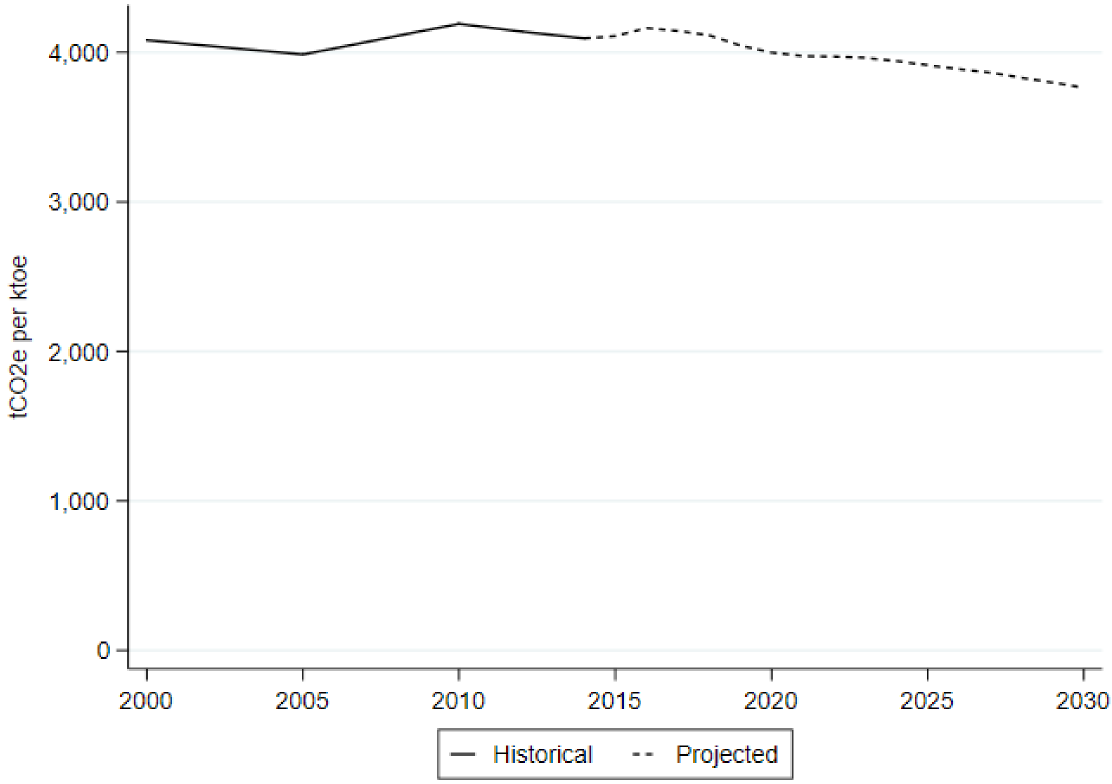

Figure C.12. Emission intensity of TPES in Mexico

Panama

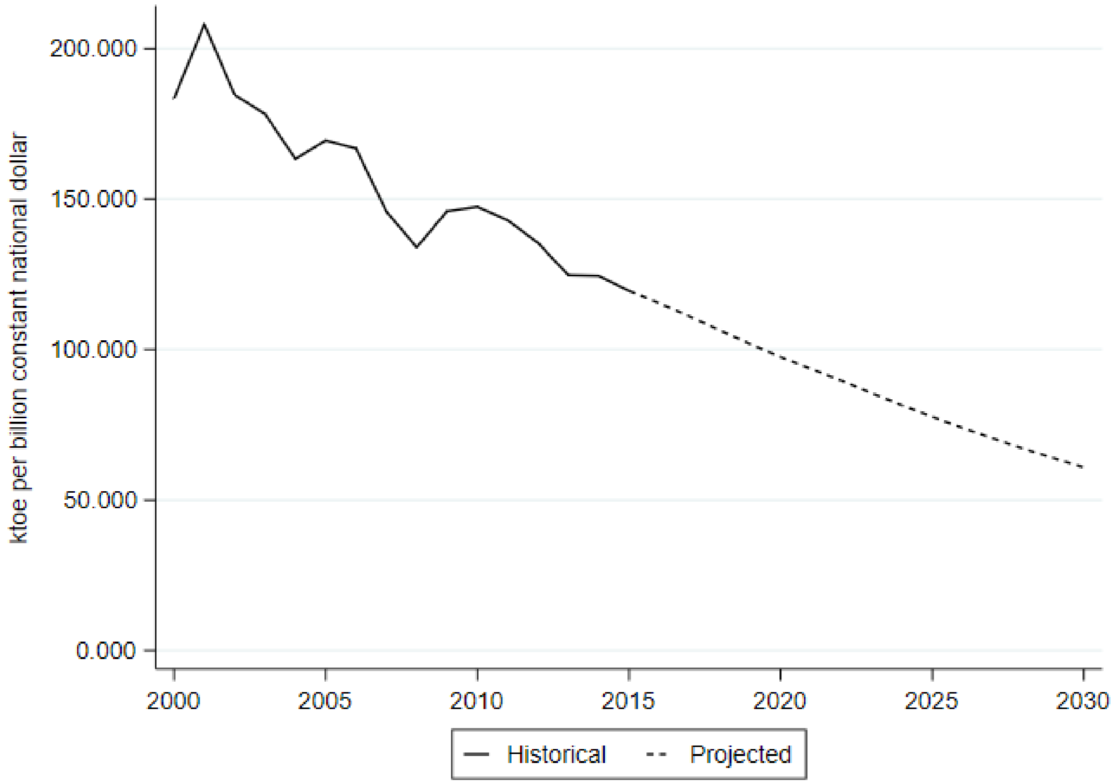

Figure C.13. Energy intensity of GDP in Panama

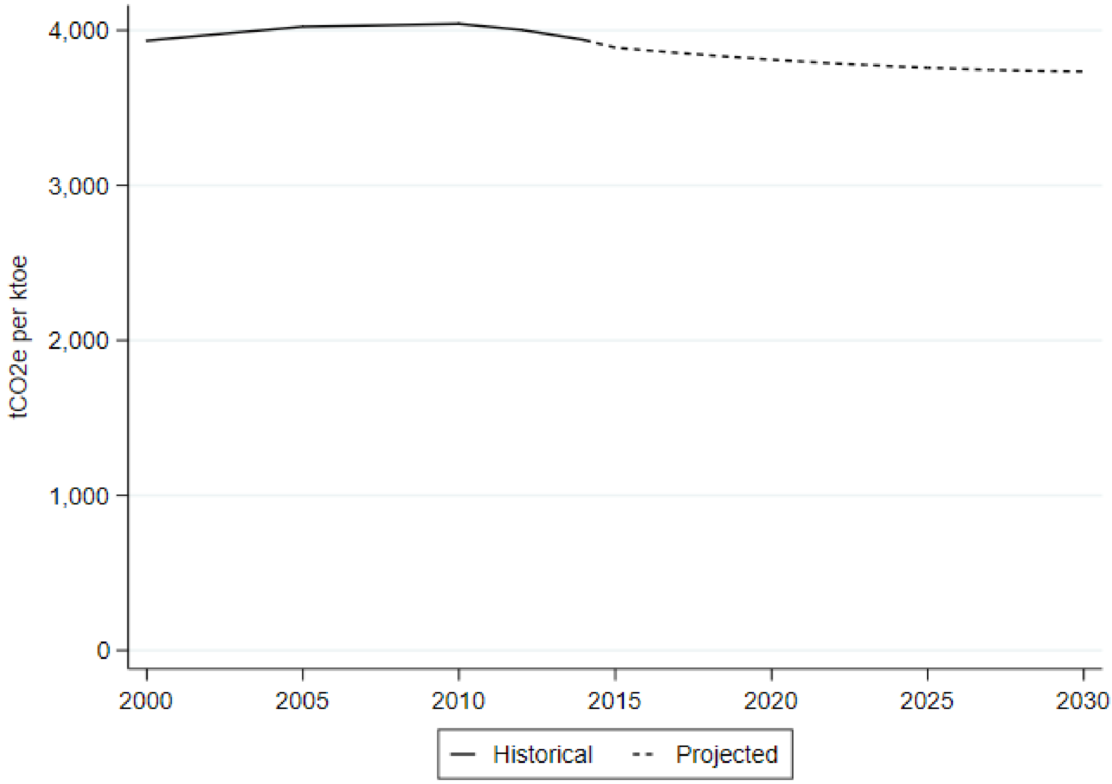

Figure C.14. Emission intensity of TPES in Panama

Peru

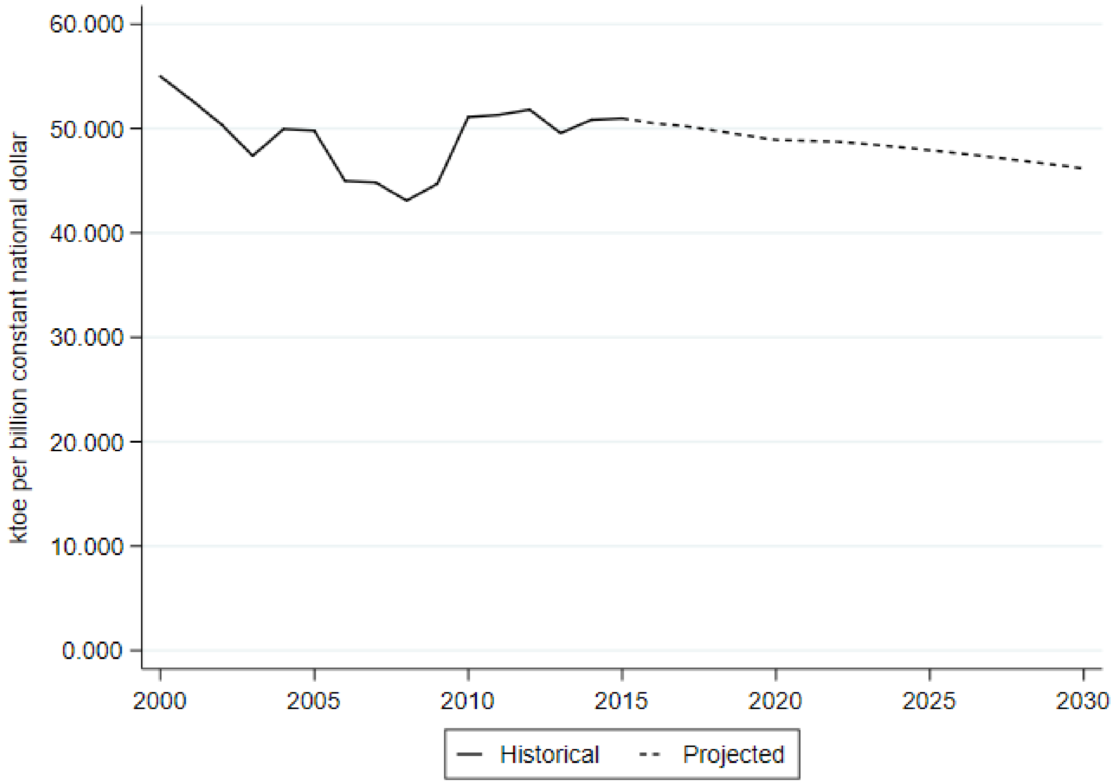

Figure C.15. Energy intensity of GDP in Peru

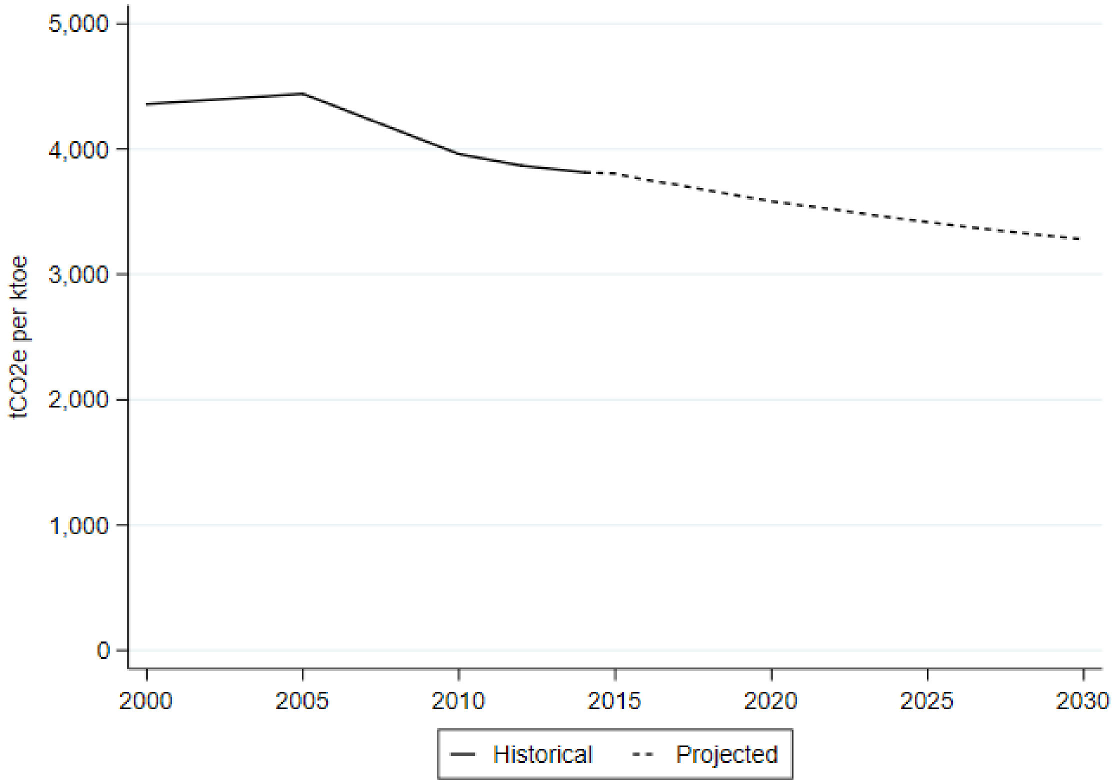

Figure C.16. Emission intensity of TPES in Peru

Uruguay

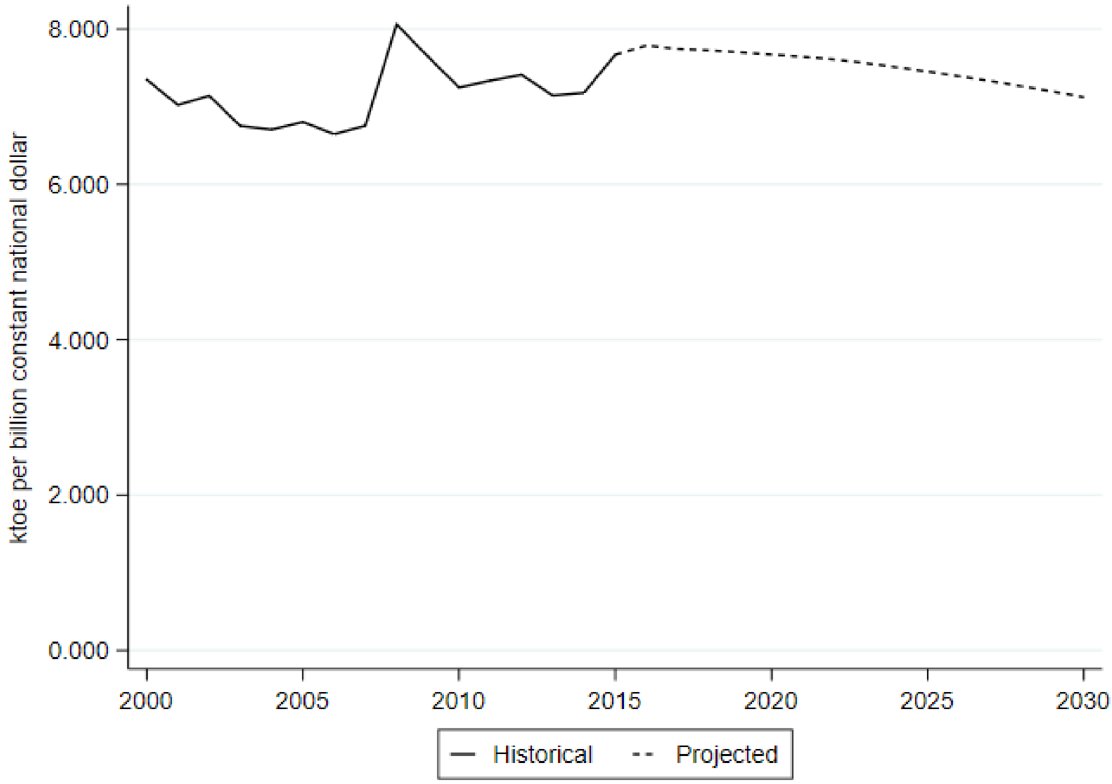

Figure C.17. Energy intensity of GDP in Uruguay

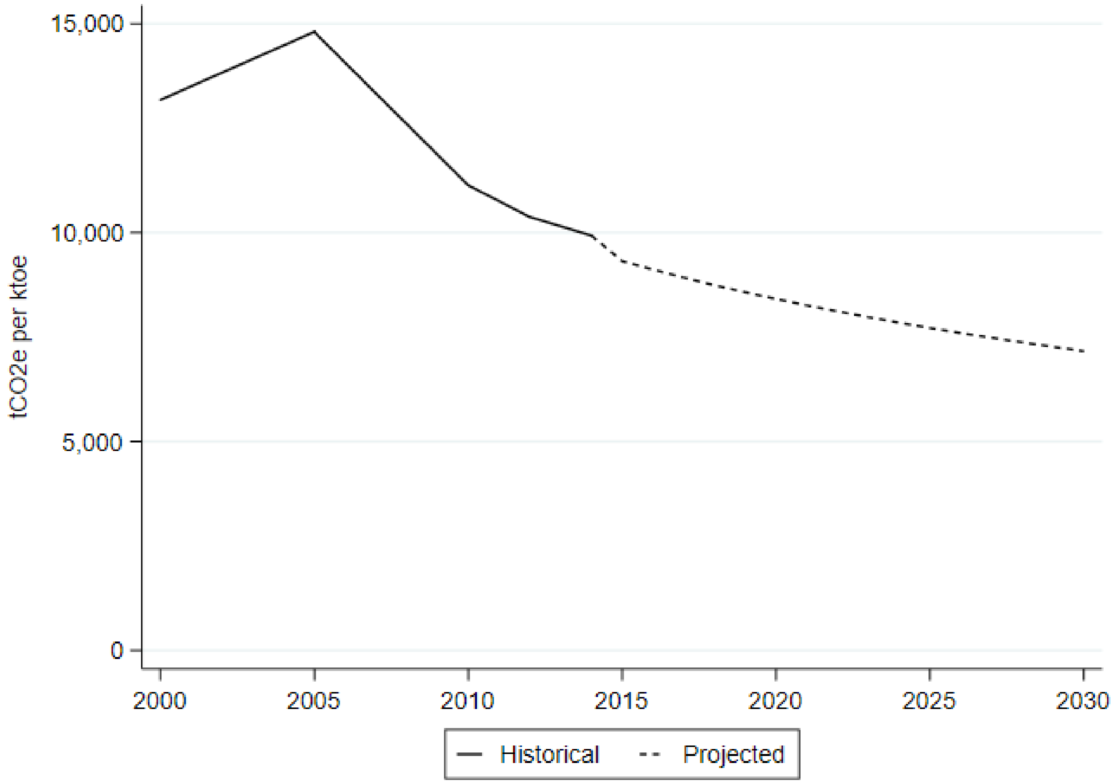

Figure C.18. Emission intensity of TPES in Uruguay

Venezuela

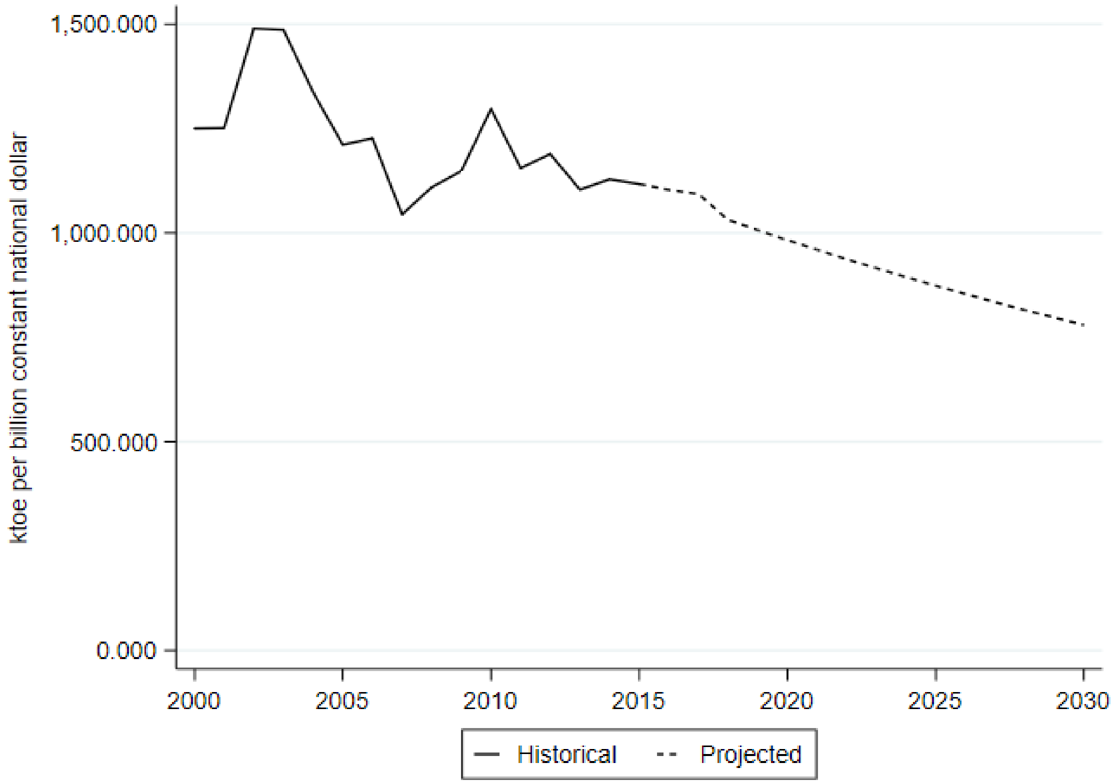

Figure C.19. Energy intensity of GDP in Venezuela

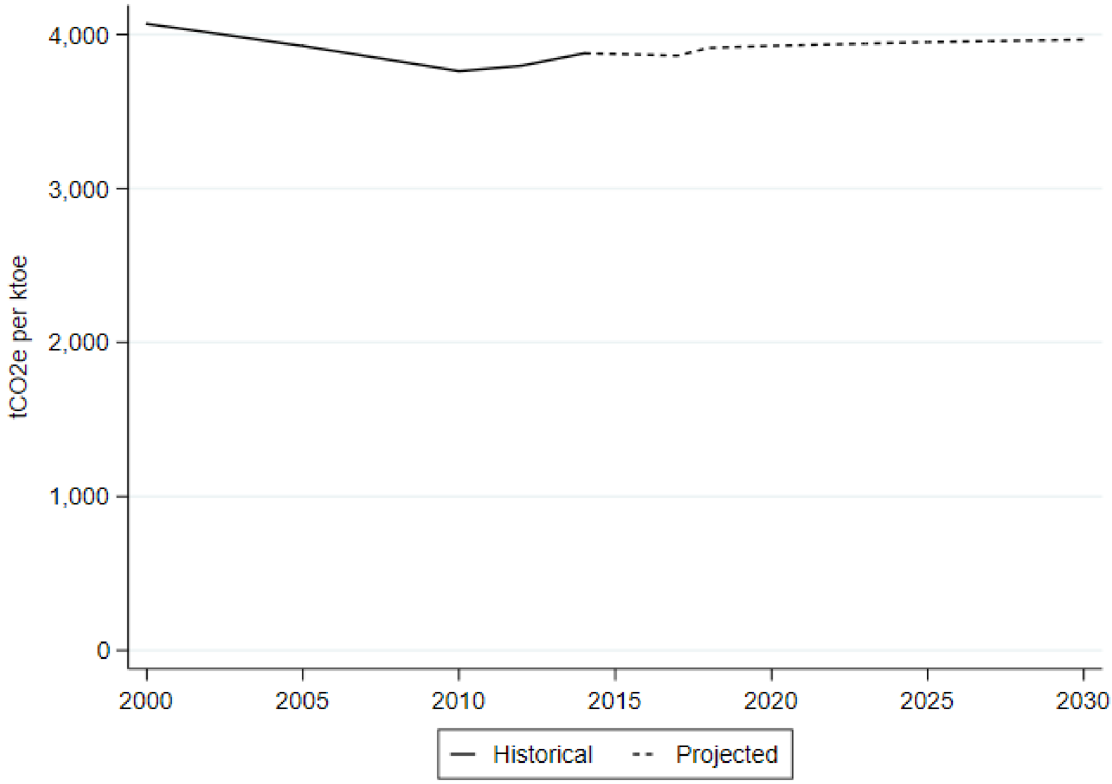

Figure C.20. Emission intensity of TPES in Venezuela

Appendix D. Country-reported emissions

For comparison purposes, below we provide GHG emissions by sector from both IEA (2017c) and country reports to the UNFCCC. Table D.1 summarizes emissions by sector and country, and includes the year of the emissions data recorded for each country. Figure D.1 illustrates total GHG emissions while Figures D.2–D.5 depicts emissions in the waste, industry, agriculture, and waste sectors. Note that the IEA and country methods may differ for emissions accounting and distribution across sectors.

Table D.1. Comparison of reported emissions by sector

		Energy			Industry		Agriculture		Waste		Total Excl. LULUCF			Total % Diff from Ctry	
Country	Year	MIT	IEA	Ctry	IEA	Ctry	IEA	Ctry	IEA	Ctry	MIT	IEA	Ctry	MIT	IEA
Argentina	2012	216	209	183	11	15	127	119	10	21	364	358	339	8%	6%
Brazil	2010	479	416	371	56	9	573	407	86	54	1194	1132	842	42%	35%
Chile	2010	78	72	69	6	6	13	13	10	4	108	102	93	16%	10%
Colombia	2012	87	82	78	4	10	58	40	11	14	160	155	142	13%	9%
Ecuador	2010	41	41	36	2	3	17	15	3	3	62	63	56	11%	12%
Mexico	2010	517	488	480	106	45	100	70	26	28	749	719	623	20%	15%
Panama	2000	6	5	5	0	1	3	3	1	1	10	9	10	4%	-3%
Peru	2010	47	46	41	4	6	21	26	5	8	77	77	81	-4%	-5%
Uruguay	2010	7	7	6	2	1	34	27	3	1	46	46	35	32%	32%
Venezuela	2010	220	210	203	10	27	35	36	8	6	272	263	273	0%	-4%

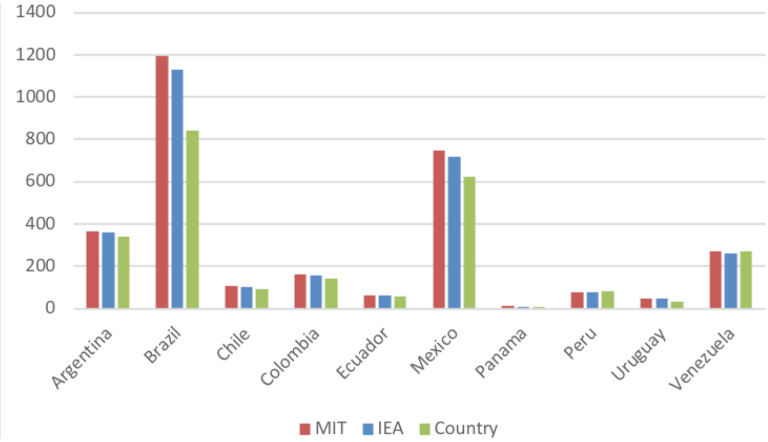

Figure D.1. Comparison of reported economy-wide GHG emissions (excluding LULUCF)

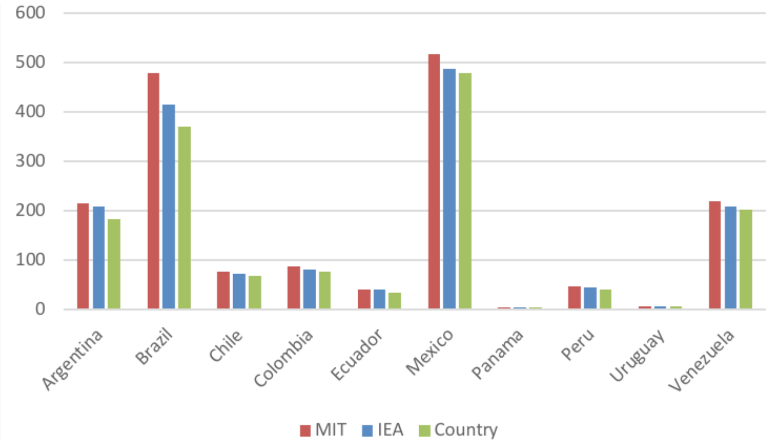

Figure D.2. Comparison of reported GHG emissions from the energy sector

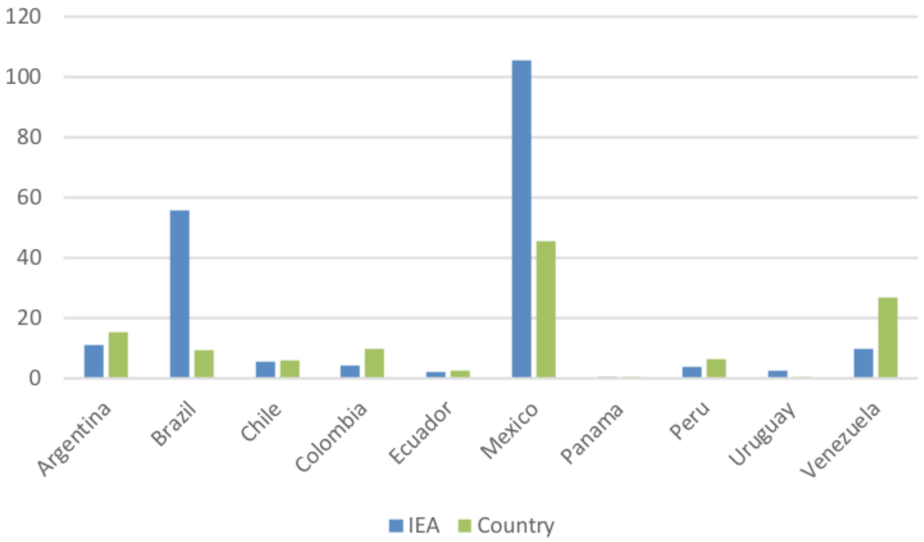

Figure D.3. Comparison of reported GHG emissions from the industry sector

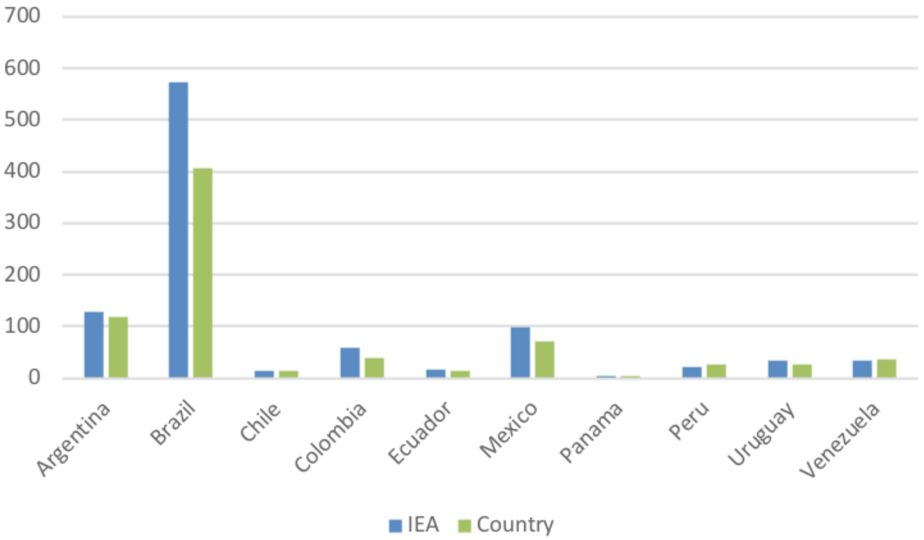

Figure D.4. Comparison of reported GHG emissions from the agriculture sector

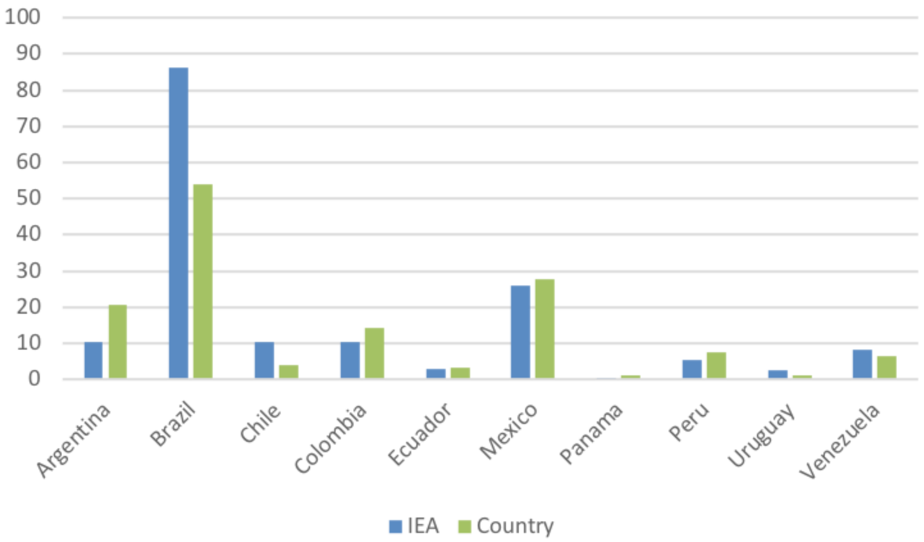

Figure D.5. Comparison of reported GHG emissions from the waste sector

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.

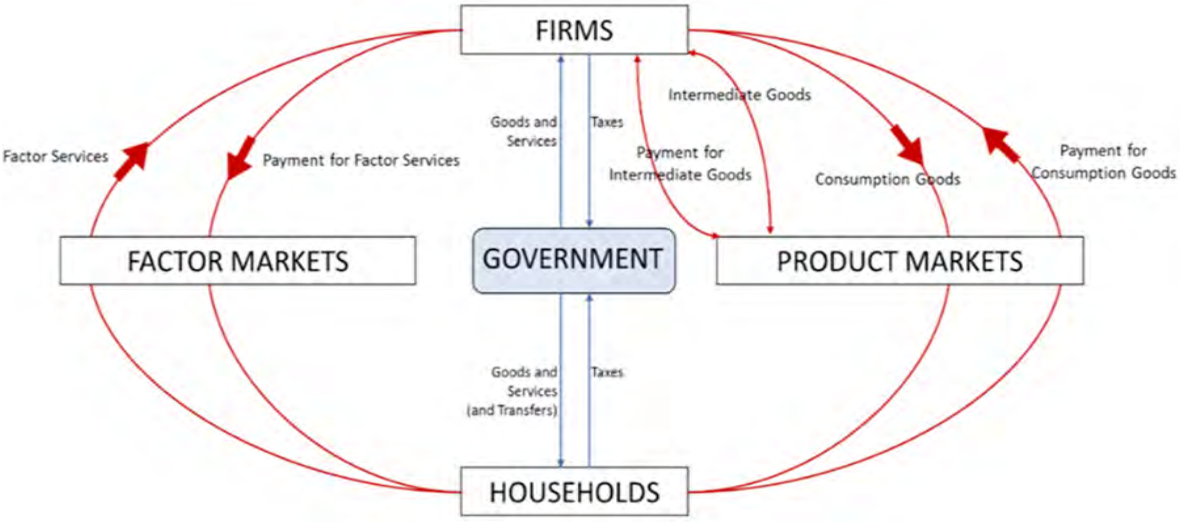

Figure E.1. The structure of an AGE Model.

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. Estimated emissions targets for Colombia

For Colombia, we approximate national estimations, excluding of those from LULUCF, consistent with unconditional and conditional emissions targets using the following procedures.

1. **Colombia's Third National Communication to the UNFCCC (IDEAM *et al.* 2017) estimates that BAU emissions in 2030 from all sources (including LULUCF) are 332 $MtCO_2e$.**
2. **Colombia's Third National Communication estimates that BAU deforestation accounts for 83 $MtCO_2e$ in 2030**
3. **Combining (1) an (2), estimated BAU emissions from all sources excluding LULUCF are 332 – 83.435 = 248.565 $MtCO_2e$.**
4. **According to Colombia's Third National Communication, emission reductions of 32.4 $MtCO_2e$ are planned from deforestation**
5. **Combining (2) and (4), forestry emissions in the unconditional and conditional scenarios = 83.435 – 32.4 = 51.035 $MtCO_2e$.**

6. Colombia's unconditional pledge is to reduce economy-wide emissions by 20% relative to BAU. According to (1) and (5), this results in an unconditional emissions target of 332×0.8 – 51.035 = 214.565 $MtCO_2e$.
7. Colombia's conditional pledge is to reduce economy-wide emissions by 30% relative to BAU. According to (1) and (5), this results in a conditional emissions target of 332×0.8 – 51.035 = 181.365 $MtCO_2e$.

E.3. Additional results from the economy-wide analyses

Table E.1. Argentina: GHG emissions in 2030, $MtCO_2$

	BAU	RPS	CON-ALL	CON-SEL	CON-EST	CON-SEL-DIG
CO_2, combustion	210.1	183.7	181.9	148.4	193.4	181.6
CO_2, non-combustion	11.8	11.7	8.8	6.9	8.1	8.9
CH_4	41.6	41.5	31.6	41.3	28.8	31.7
N_2O	114.2	114.2	86.7	112.7	78.9	87.0
F-gases	1.2	1.2	0.9	0.7	0.8	0.9
Total	378.9	352.3	310.0	310.0	310.0	310.0

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

	BAU	RPS	CON-ALL	CON-SEL	CON-EST	CON-SEL-DIG
Coal	15.3	9.1	8.7	1.4	10.8	8.8
Gas	160.2	69.3	69.6	28.6	140.3	72.5
Oil	3.6	3.6	3.6	3.6	3.6	3.6
Hydro	27.8	27.8	27.8	27.8	27.8	27.8
Wind & solar	51.4	51.4	51.4	51.4	51.4	51.4
Other renewables	48.3	54.4	54.4	54.2	49.6	59.3
Total	306.6	215.5	215.5	167.0	283.5	223.4

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

	BAU	RPS	CON-ALL	CON-SEL	CON-EST	CON-SEL-DIG
Coal	4.18	2.63	2.55	0.78	3.04	2.47
Gas	50.50	41.42	40.90	28.83	45.57	40.84
Oil	40.38	40.47	40.38	39.19	39.85	40.43
Hydro	7.17	7.16	7.16	7.16	7.17	7.16
Wind & solar	4.88	4.28	4.27	3.90	4.71	4.37
Other renewables	4.08	4.61	4.60	4.59	4.20	5.02
Total	111.20	100.57	99.87	84.44	104.53	100.29

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.

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

	BAU	RPS	CON-ALL	CON-SEL	CON-EST	CON-SEL-DIG
CO_2, combustion	108.1	94.5	92.0	68.6	98.1	91.9
CO_2, non-combustion	6.9	6.8	5.1	3.7	4.8	5.1
CH_4	24.2	24.2	18.7	24.0	17.4	18.7
N_2O	85.8	85.7	65.5	85.0	61.0	65.5
F-gases	0.2	0.2	0.1	0.1	0.1	0.1
Total	225.3	211.3	181.4	181.4	181.4	181.4

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

	BAU	RPS	CON-ALL	CON-SEL	CON-EST	CON-SEL-DIG
Coal	13.1	1.8	1.8	0.3	10.7	1.8
Gas	27.7	7.1	7.1	4.1	27.2	7.1
Oil	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	56.8	56.8	56.8	56.8	56.8	56.8
Other renewables	2.7	3.2	3.2	3.2	2.7	3.5
Total	100.4	69.0	69.0	64.4	97.5	69.3

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

	BAU	RPS	CON-ALL	CON-SEL	CON-EST	CON-SEL-DIG
Coal	13.93	13.62	13.60	13.30	13.86	13.60
Gas	16.73	14.25	13.90	9.96	15.57	13.87
Oil	13.93	13.62	13.60	13.30	13.86	13.60
Hydro	4.74	4.74	4.74	4.74	4.74	4.74
Other renewables	0.22	0.26	0.26	0.26	0.23	0.29
Total	45.58	40.88	40.16	33.88	42.73	40.15

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.