JISEA Research Highlight

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# Options for Resilient and Flexible Power Systems in Select South American Economies

*Full report available at* https://www.nrel.gov/docs/fy20osti/75431.pdf

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## Summary of Findings

This research revealed that representative South American countries (Argentina, Brazil, Chile, and Colombia) with relatively high levels of hydropower generation and rapidly growing shares of variable renewable energy are facing new challenges in providing flexible, resilient, sustainable, and affordable electricity. A variety of options exist to achieve these goals including market design changes, deeper integration of distributed energy resources (e.g., demand response and energy storage), and increased use of natural gas on the margin.

## Snapshot

- The El Niño and La Niña hydrological phenomena are changing the way electric power systems are planned and operated in key South American countries. In systems with growing shares of variable renewable energy, these changes are especially pronounced. Argentina, Brazil, Chile, and Colombia are all seeking new ways to add greater flexibility and resiliency to their power systems.
- Natural gas used in power generation is growing in most of these countries and is one option to help achieve electricity sector goals—it is an especially effective way to complement the variability of wind and solar. Development of the Vaca Muerta natural gas formation in Argentina is perhaps the greatest source of promise and uncertainty regarding the long-term role of natural gas in South America and beyond.
- Variable renewable energy is an increasingly popular option to help ensure that dammed hydropower resources are available at key times of the year. Wind and solar are growing especially rapidly in Brazil and Chile although Argentina and, most recently, Colombia, have also seen growing deployment.
- Contract terms for markets in liquified natural gas have become more liquid and flexible over the past five years, while alternatives to land-based liquefaction and regasification infrastructure have allowed South American countries to enjoy the benefits of short-term natural gas use without having to invest in permanent land-based infrastructure.

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## Introduction

Power systems around the globe are changing rapidly due to a confluence of technological, social, meteorological, and economic drivers (21CPP and IEA 2019, BNEF 2019, IEA 2018, DNV GL 2019). Wind and solar, especially paired with competitive auction procurements, have become the lowest cost, new generation options in many regions of the world. In several countries, the emergence of plentiful and affordable unconventional gas is leading to the retirement of incumbent generators and greater liquidity and flexibility in liquified natural gas (LNG) markets. Battery storage, demand response, electric vehicle charging and other distributed energy resources (DERs) are altering the way power systems are planned and operated. Few locales, if any, are immune to these dynamics.

These changes are highlighting the need for flexibility and resilience in energy systems. This is seen clearly in select South American countries that have traditionally relied heavily on large (dammed) hydropower stations and that now also see rapid growth in variable renewable energy (VRE) sources. Over the past decade, some of these countries have seen dramatic changes in hydropower availability because of variations in precipitation associated with El Niño and La Niña hydrological phases. In Brazil, for example, hydropower plants typically provided 80% of annual power generation needs before 2010, but in the El Niño years of 2014-2015, their contribution fell to 64% (EPE 2019a). Similar situations exist in Colombia and to a much lesser extent in Argentina and Chile. The rapidly changing capacity mix in the four countries studied here is summarized in Figure 1.

This highlight report summarizes a detailed research report about opportunities for select countries in South America to adapt to these buffeting forces to ensure reliable, affordable, sustainable, and resilient power

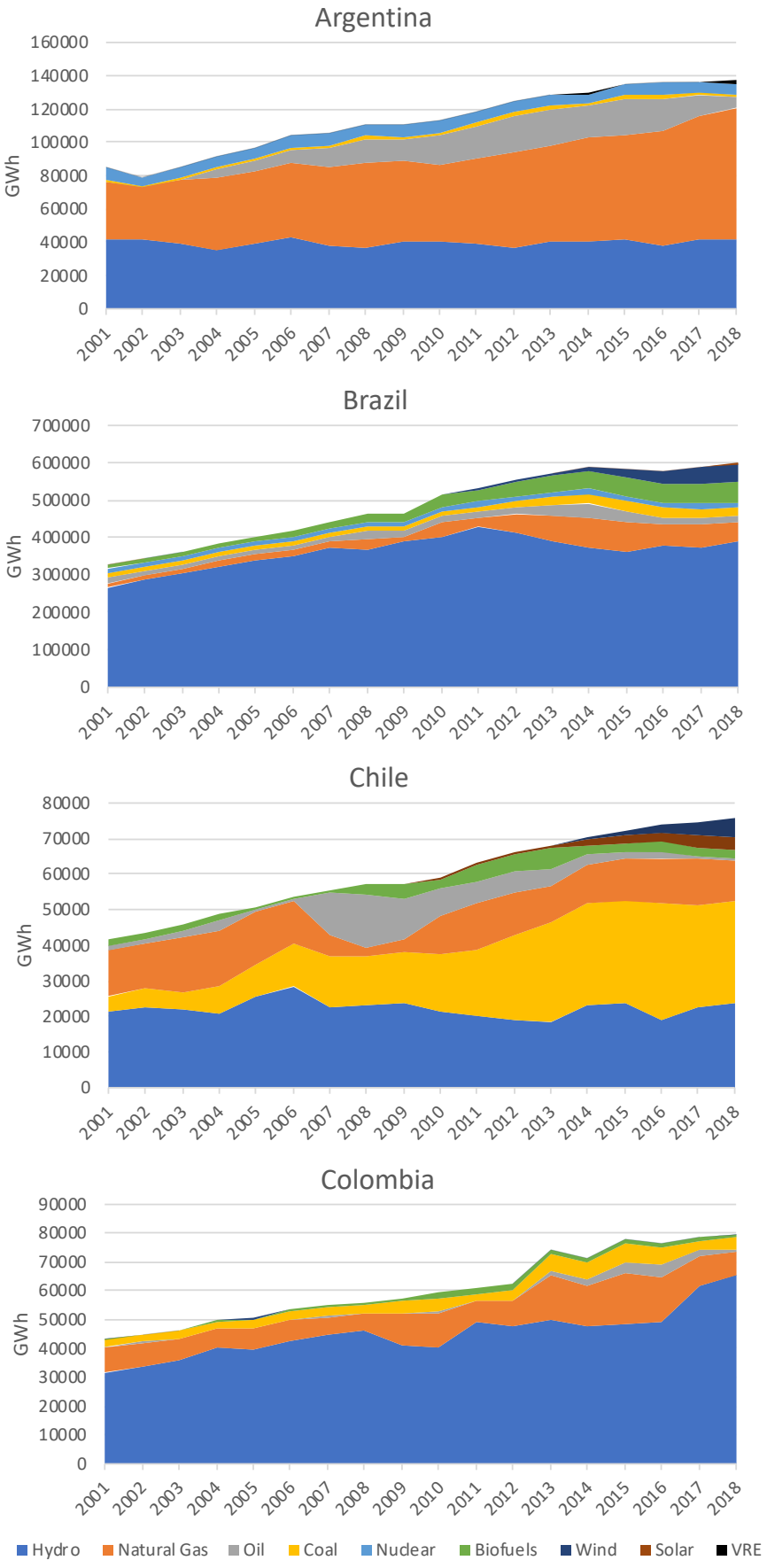


Figure 1. Evolving generation mixes in Argentina, Brazil, Chile and Colombia, 2001-2018. Source: CAMMESA (2019), CNE (2019), EPE (2019), IEA (2019), XM (2019)

systems (do Prado, et al. 2019). Special attention is placed on the potential role for natural gas to help ensure flexible and resilient power. Argentina, Brazil, Chile, and Colombia are all vying to play stronger leadership roles in the continent and all have stated increasingly bold commitments to sustainable development.

Figure 2 summarizes the approach taken in this study to consider options in both electricity and natural gas sectors for providing flexibility and resiliency over different time scales. The primary issues and time scales of interest are described on the left for the main generation options in South America while the main policy options for the electricity and natural gas sectors are provided on the right.

Table 1 compares and contrasts risks and constraints associated with the need for greater flexibility in the power sectors of all four countries. Brazil and Colombia are the most vulnerable to hydropower output impacts from El Niño and La Niña events. Brazil and Chile are experiencing the fastest growth in VRE deployment. Currently, Argentina is most exposed to risk from fuel-supply uncertainty, although Brazil, Chile, and Colombia are not immune to these risks. All countries except Brazil face significant challenges in extracting greater flexibility from their existing thermal fleet of generators. Argentina probably has the best chance of continuing to build large hydropower plants but, even there, public opposition to that choice is still high.

Table 2 summarizes some of the key barriers and challenges to further development of the electricity and natural gas sectors in the four countries targeted in this study. Relative to the others, Argentina faces challenges because of aging infrastructure (exemplified by a blackout in June of 2019) and from directing sufficient revenue for investment in both electricity and gas—a situation that is primarily due to its prolonged economic instabilities (i.e., high inflation rates and currency fluctuation) and market distortions associated with subsidies. All four countries face limitations associated with transmission capacity, public opposition to large hydropower plants, and market mechanisms to promote greater

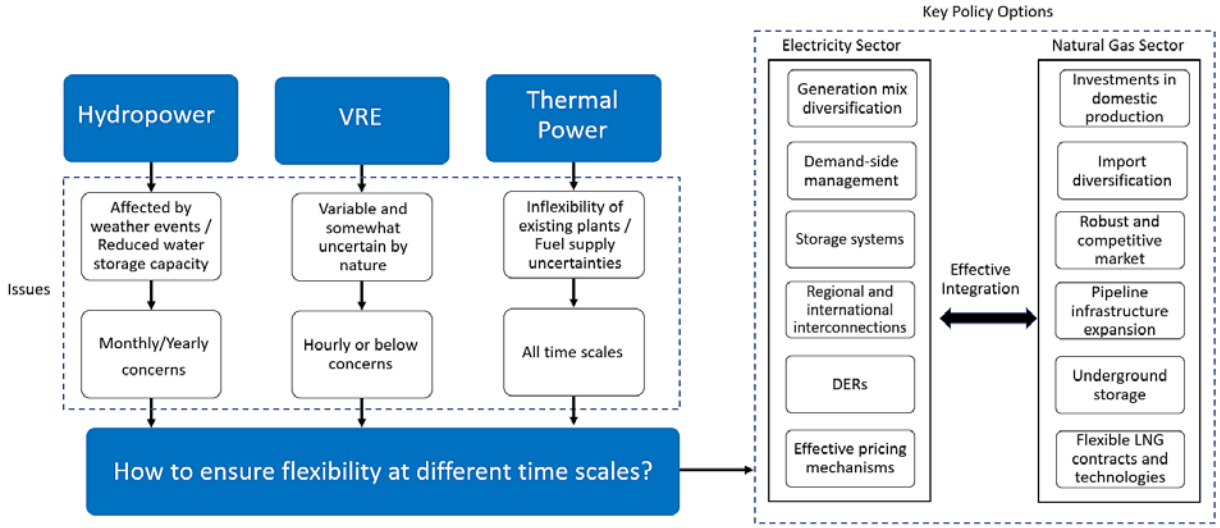


Figure 2. Flexibility issues and options in power systems of key South American countries.

**Table 1 – Risks and Constraints for More Flexible Power Generation in Select South American Countries**

| | | Argentina | Brazil | Chile | Colombia |
|---|---|---|---|---|---|
| **Flexibility Catalysts** | Weather events affecting hydropower | Medium | High | Medium | High |
| | Increasing adoption of run-of-the-river power plants | Medium | High | Medium-High | High |
| | Increasing VRE integration | Medium | High | High | Low |
| | Thermal power generation inflexibility | High | Low | High | High |
| | Fuel-supply uncertainties | High | Medium | Medium | Medium |

flexibility in the electricity sector. In the gas sector, all four countries face limitations in underground storage and pipeline capacity. Chile is relatively unique because it is the only country with insufficient domestic gas reserves to be developed over the long-term while Brazil faces techno-economic challenges associated with developing its offshore resources.

Figure 3 illustrates the changing demand for imported LNG among the main countries in this study. While Brazilian imports of LNG rose sharply during the drought years of 2012-2015, the fall-off in Argentinian imports resulted more from rising domestic production in the Vaca Muerta play.

**Table 2 - Barriers and Challenges for Electricity and Natural Gas Development in Select South American Countries**

| | Issue | Argentina | Brazil | Chile | Colombia |
|---|---|---|---|---|---|
| Relative barriers and challenges in the electricity sector | Aging infrastructure | x | | | |
| | Transmission capacity limitations | x | x | x | x |
| | Insufficient revenue for investment | x | | | |
| | Public opposition to hydropower plants | x | x | x | x |
| | Limited international interconnections | | | x | x |
| | Lack of market mechanisms to promote greater flexibility | x | x | x | x |
| | Demand concentration in specific regions | x | | x | |
| Relative barriers and challenges in the natural gas sector | Techno-economic challenges associated with domestic production | | x | | |
| | Insufficient long-term domestic reserves | | | x | |
| | Lack of underground storage infrastructure | x | x | x | x |
| | Pipeline capacity limitations | x | x | x | x |
| | Insufficient revenue for investment | x | | | |

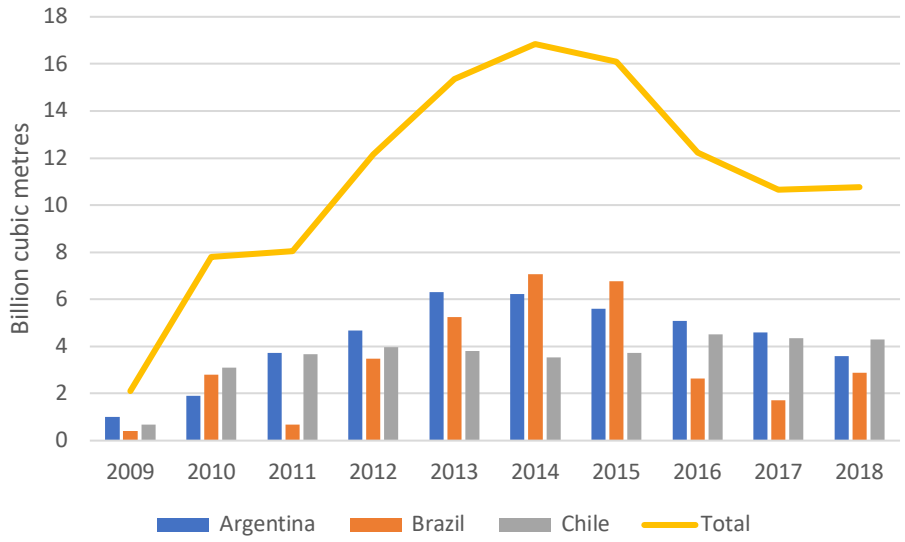


Figure 3. LNG imports in selected countries of South America and total for South America and Central America. Source: Data from BP (2019)

## Country-Specific Options

### Argentina

The Argentinian energy sector currently faces strong headwinds due to the shrinking economy, high inflation, and the depreciating peso. Nonetheless, Argentina has very ambitious plans to develop the Vaca Muerta formation and build infrastructure to move gas to market. This play has the potential to not only supply Argentina's domestic needs but could—under ideal conditions—allow Argentina to export gas both by pipeline to Chile, Brazil, and potentially others, and to ship it in the form of LNG to other countries. Development of the resource, and the infrastructure needed to move the gas considerable distances, is challenged by the current economic difficulties, regulatory risks, and decades of market distortions that impact the flow of investments. Addressing remaining market distortions so that investment will flow is a key challenge for Argentinian policymakers, although this is difficult in a period of economic crisis. Adding more natural gas pipelines and underground storage appears to be a high priority for the country given the seasonal imbalances in the market, as shown in Figure 4.

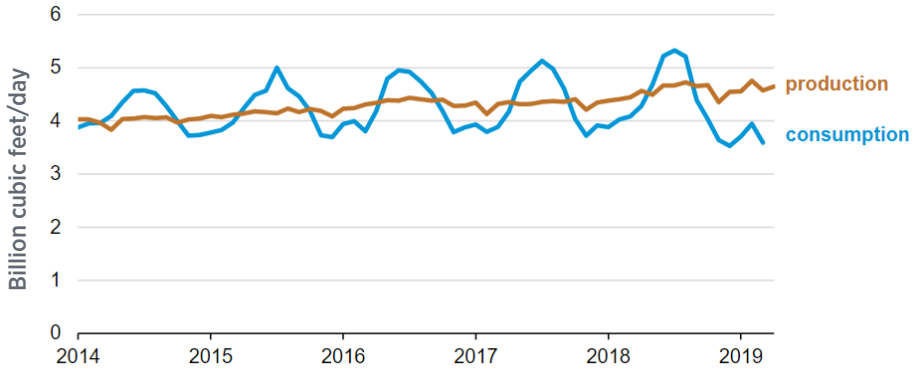


Figure 4. Monthly natural gas production and consumption in Argentina. Source: U.S. EIA (2019)

Over the past few years, Argentina has taken successful steps to accelerate the deployment of renewables through its auction programs. Continued focus on deploying VRE can be a source of low-cost electricity that offsets the need for gas- or oil-fired generation, although siting and constructing new transmission lines remains a challenge.

Demand-side energy efficiency activities may be one of the least costly ways for Argentina to support reliable electricity services, especially given the demand growth that occurred during the peak years of previous energy subsidies. Coordinated planning of energy infrastructure using state-of-the-art modeling tools remains an important task for Argentinian decision-makers. The dynamics and diversity of Argentina's electricity sector are summarized in Figure 5.

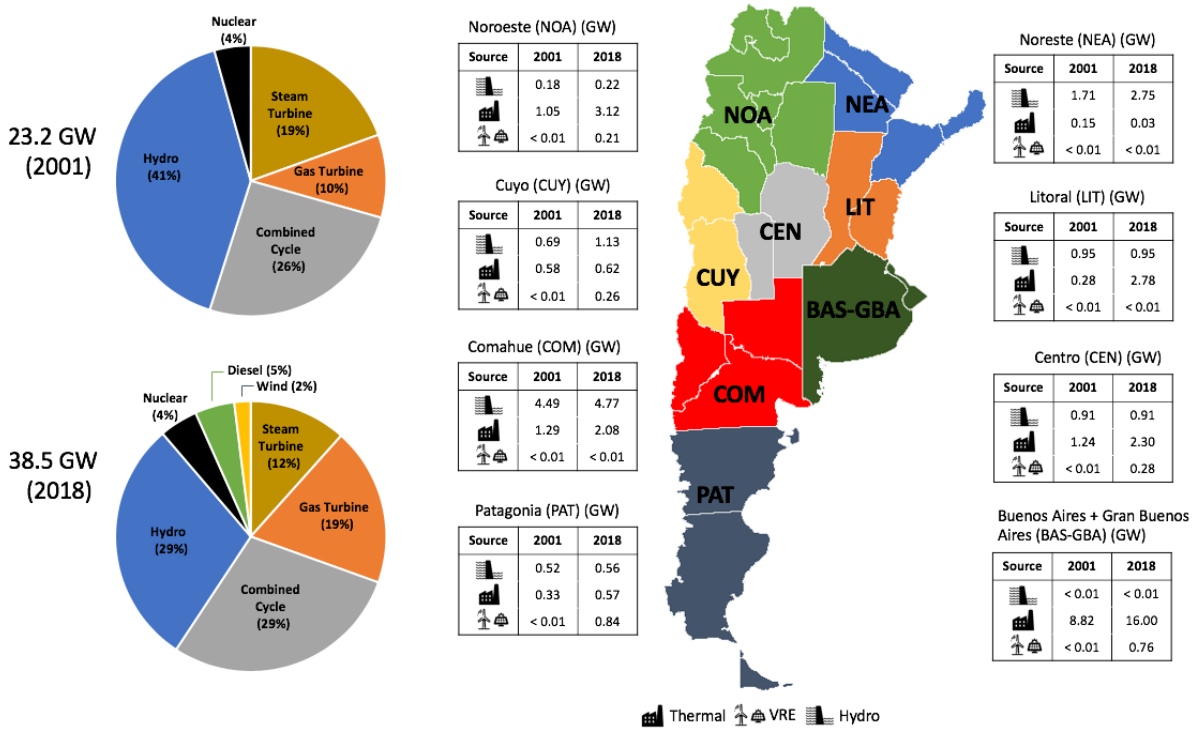


Figure 5. Total and regional installed capacity in Argentina in 2001 and 2018.

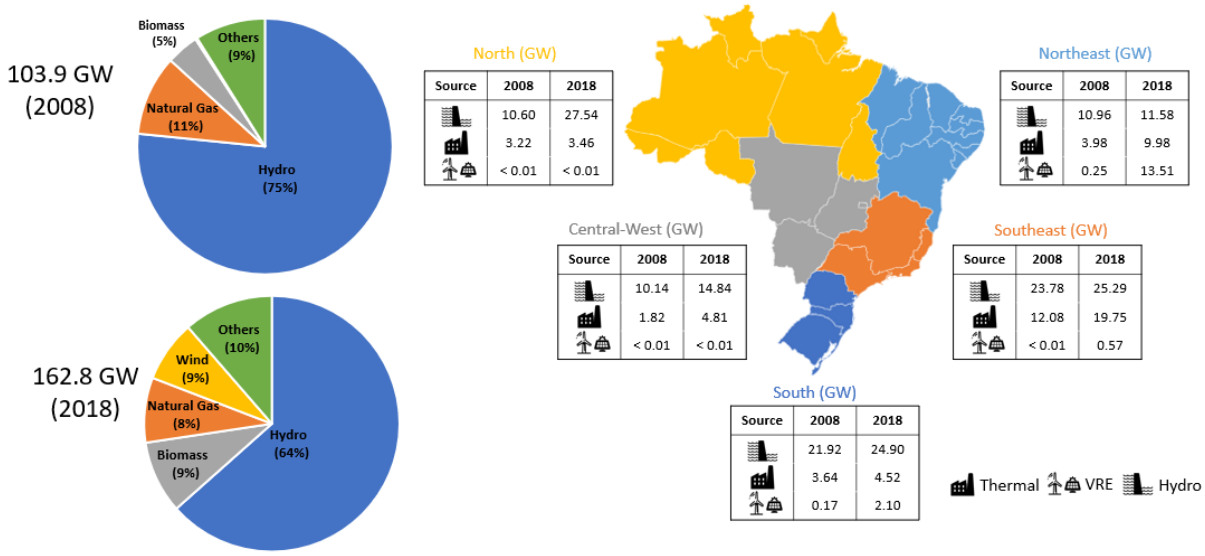


Figure 6. Total and regional installed capacity in Brazil in 2008 and 2018. Source: Data from EPE (2019)

## Brazil

Brazil's power sector is growing and diversifying rapidly, as shown in Figure 6. Hydropower's share of total generation has fallen since about 2011. Brazil has sophisticated energy planning capability and has installed more non-hydro renewables than any other South American country over the past decade. It is working to integrate more VRE and demand response capabilities into the grid, and reforming electricity pricing mechanisms to better reflect supply and demand over shorter time intervals. It may also benefit from greater interconnection of transmission lines with neighboring countries and greater integration of distributed energy resources (DERs).

Brazil is working to develop its considerable offshore natural gas resources and, like Argentina, would benefit from more gas infrastructure, especially large-scale underground storage. It has taken advantage of floating storage and regasification units (FSRUs) to import LNG during periods of peak demand without having to commit to more permanent land-based infrastructure. This reliance on FSRUs is expected to grow over the coming years, at least until obtaining more certainty over development prospects for offshore resources. Brazil is also taking steps to introduce more competition within the natural gas sector and diversify control over production, transmission, and distribution.

The use of natural gas in Brazil is summarized in Figure 7. Gas-fired power generation has grown rapidly over the past decade, but at least temporarily peaked during the El Niño drought year of 2014.

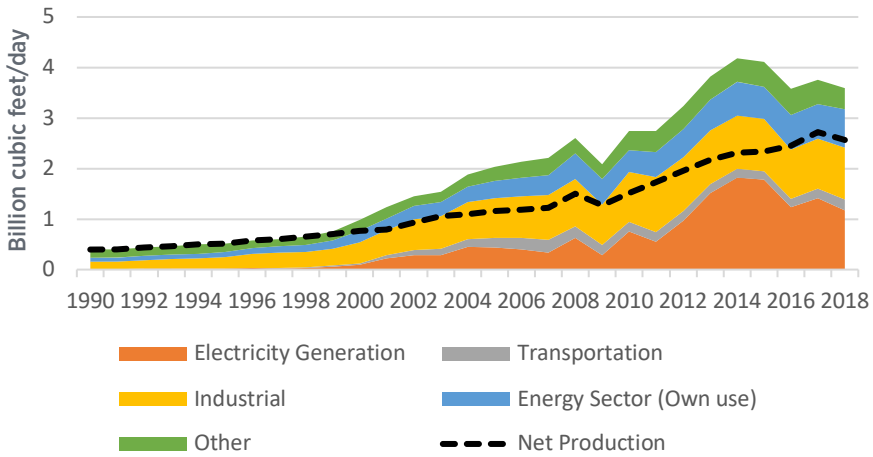


Figure 7. Natural gas consumption in Brazil by sector versus net production. Source: Data from EPE (2019)

## Chile

Chile has been at the global forefront in introducing market-oriented liberalization and privatization in its energy sector. Chile faced a gas crisis starting in 2004 (when Argentina abruptly reduced pipeline exports) that had profound impacts on the country. The immediate response was to briefly rely on petroleum products in electricity generation to make up for the lost gas supply and to construct several LNG import terminals. Coal generation also grew rapidly over the past decade as a longer-term substitute for natural gas, but the government announced in mid-2019 that it would phase out coal generation by 2040. Figure 1 summarizes these changes.

Chile has also seen rapid growth in VRE since 2014 and has extremely high-quality solar resources in the north and abundant wind in the south. Planning and constructing transmission capacity to move the power to the demand centers in and around Santiago (and to mining load centers in the northern region for night-time operations) remains a top priority for Chilean decision-makers. The share of electricity coming from hydropower plants with large reservoirs has fallen rapidly as the country moved to greater reliance on run-of-the-river configurations, which are not capable of providing medium- and long-term flexibility services. Chile's generation capacity has doubled over the past decade, with thermal potential growing fastest, followed by VRE, then hydro, as shown in Figure 8.

Chile is likely to rely more heavily on imported natural gas in the near term given the shrinking availability of hydropower and the planned phase-out of coal. It has plans to build new LNG import infrastructure and recently began to import gas again from Argentina via pipeline. Greater interconnection of electricity lines with neighboring countries, use of demand response, and deployment of a variety of energy storage options are three other options for Chile to improve flexibility and resilience in the power sector.

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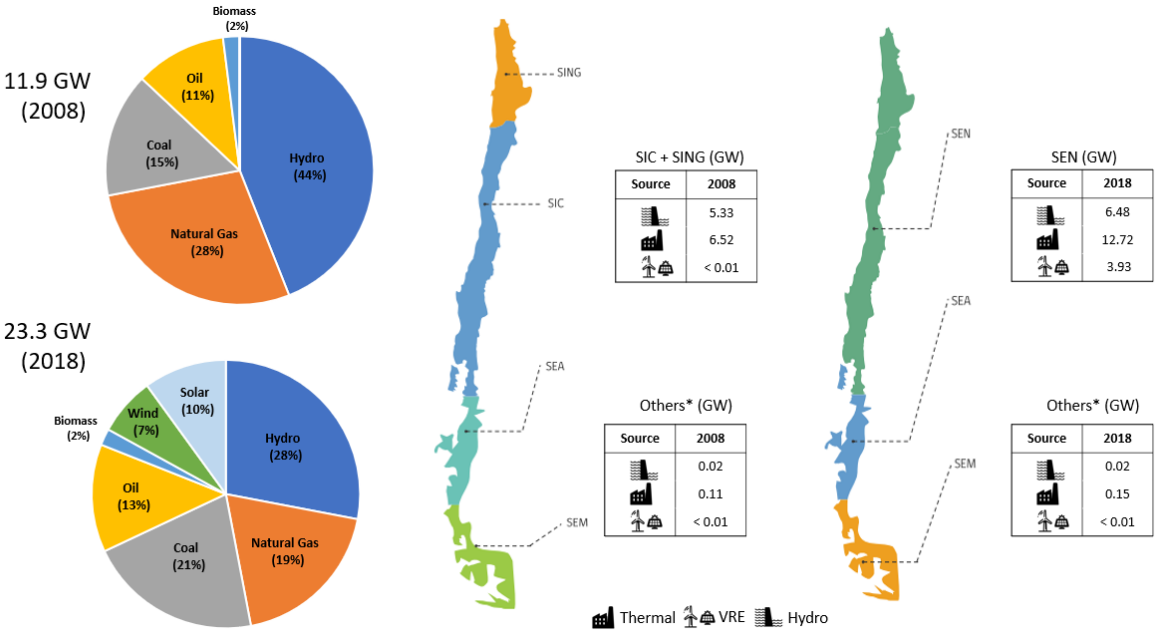


Figure 8. Total and regional installed capacity in Chile in 2008 and 2018. Source: Data from CNE (2019)

## Colombia

Like most of Brazil, Colombia is heavily dependent on hydropower and is exposed to drought conditions during El Niño years. The capacity share of hydropower has been rising recently despite the government's attempt to diversify the mix. It has relatively small shares of coal and natural gas generation, as shown in Figure 9. In late 2019, Colombia had its first successful auction for new sources of wind and solar.

During one particular drought in early 2017, spot power prices rose (light blue line) when hydropower generation fell (dark blue line), as shown in Figure 10.

Colombia is a major exporter of coal, yet that fuel supplies only about 10% of the country's electricity generation mix, on par with natural gas generation. The country's natural gas production is in fairly rapid decline while demand

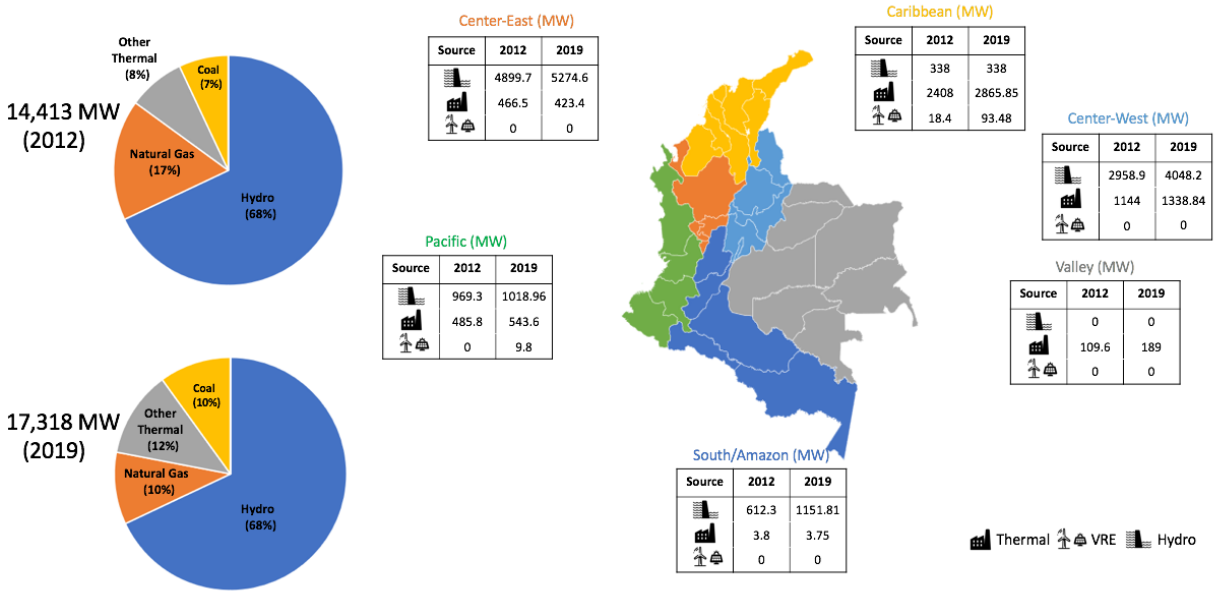


Figure 9. Total and regional installed capacity in Colombia in 2012 and 2018. Source: SIEL (2019), UPME (2017), DNP (2017)

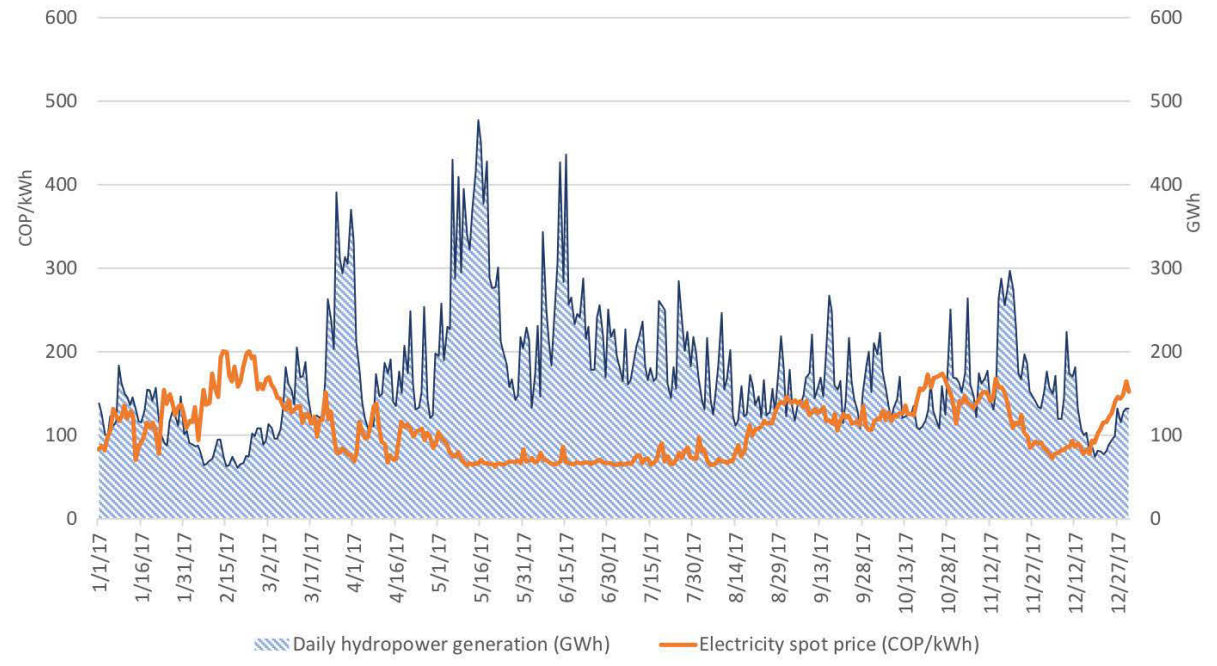


Figure 10. Spot price and hydropower generation in Colombia in 2017. Source: XM (2019)

continues to grow, leading Colombia to begin importing LNG in 2016 using FSRUs. LNG imports are expected to grow rapidly in the near future. A pipeline connects Venezuela and Colombia but no trade occurs despite the former having the largest gas reserves in South America. Both countries use the majority of their natural gas for reinjection at oil production sites to increase formation pressure. Also, like Brazil, Colombia has recently discovered significant offshore gas reserves, but analysts do not expect growth in production for at least a decade when drilling and infrastructure build-out can be completed.

Colombia has a partially liberalized electricity sector, but still provides subsidies to non-low-income consumers. It is beginning to rectify the distortions that these subsidies can cause. Colombia is the only country analyzed here that does not yet have a vibrant market for VRE deployment, although the country's first successful VRE auction held in late 2019 is likely to improve the situation. Colombia is planning for rapid growth in new renewable electricity sources to be deployed in the near term.

## Conclusion

Argentina, Brazil, Chile, and Colombia face unique challenges in building out their respective electricity sectors to achieve a resilient, reliable, and sustainable electricity system. Each country faces challenges from uncertain hydropower output, but Argentina is less exposed to these variations. All have goals to rapidly boost domestic VRE generation, and all except Chile have significant natural gas resources that they plan to aggressively develop. Argentina's Vaca Muerta formation may be the biggest uncertainty in all of South America's evolving electric power sector calculus—this promising resource base could have global repercussions on energy markets, yet the country faces significant economic and political challenges in developing it. In the meantime, imported LNG may be the most expedient option for Brazil, Chile, and Colombia on the margins given the recently improved liquidity of, and contract terms for, that fuel.

While technology and market innovations in the form of rapidly falling costs for VRE, LNG contracting, battery storage, and other distributed energy options are sometimes outpacing the institutional and policy capacity to effectively guide them, other breakthroughs could occur to better harmonize the deployment of flexibility and resiliency options. These South American countries face significant challenges in meeting future electricity sector goals, but the speed of change is occurring so rapidly that unexpected developments should be considered likely. On a positive note, each of these countries is building from a strong base of renewable hydropower into a diverse portfolio of solar, wind, and natural gas, targeting a clean and resilient power system.

## Learn More

See the released technical report on this work titled, "Options for Resilient and Flexible Power Systems in Select South American Economies." do Prado, J. Logan, F. Flores Espino. 2019. https://www.nrel.gov/docs/fy20osti/75431.pdf

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