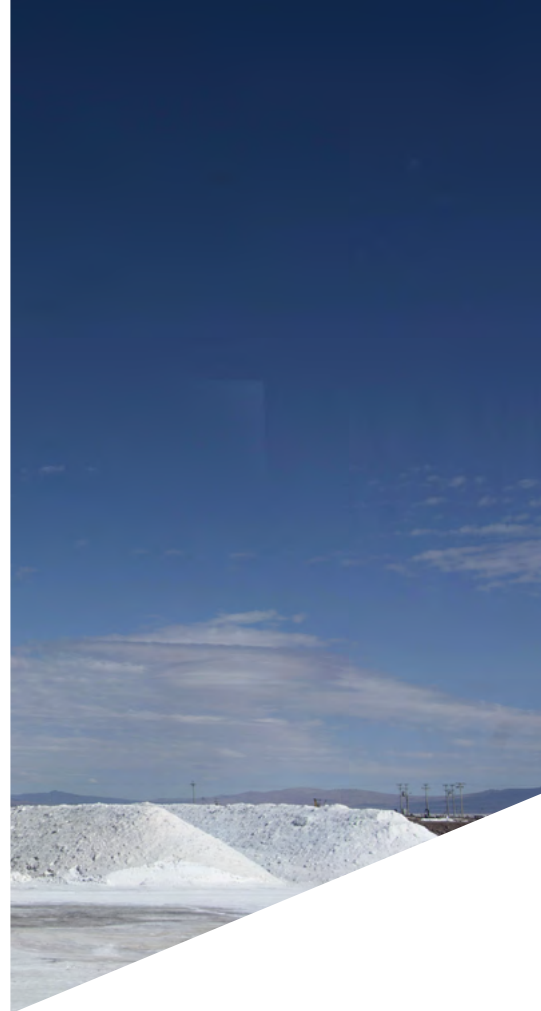


December 2019

# Chile Power System Outlook

Chile



BloombergNEF

## Foreword

*Chile has been a leader in raising awareness on the effects of climate change and the need for ambitious targets and urgent action. It was one of the first countries in the world to declare a target for renewable energy, and it is about to meet that six years ahead of schedule. It was also the first South American nation to officially declare a coal ban, unveiling an unprecedented plan to retire 1GW of capacity by 2024, closing eight of its oldest coal-fired power plants.*

*These steps established a clear path to redirecting energy investment and policies to reduce carbon emissions and Chile's heavy dependence from fossil fuels.*

*On this basis, ACCIONA is delighted to co-sponsor this insightful and profound analysis of the outlook for one of our key markets. Chile is a unique case marked by its extraordinary solar resources and the lack of any international interconnections. Deep penetration of solar will be an important part of Chile's future and so will the technical challenge to reach 100% renewable generation.*

*Solar PV, together with wind power, will steadily push fossil fuel plants out of the system on the basis purely of economics, as their growth is the optimal way to reduce system costs. Chile's electricity sector emissions have already peaked – in 2016 – and decarbonization by 2050 can be achieved smoothly with a comprehensive regulatory framework for flexibility solutions, and the correct steps to accelerate the phase-out of coal generation.*

*As the world's largest energy operator dedicated exclusively to renewable energy, ACCIONA is committed to the development of the Chilean renewables sector. We currently own 291MW of renewables in Chile: 246MW in the El Romero solar PV plant in the region of Atacama, and 45MW in the Punta Palmeras wind farm in the region of Coquimbo. In addition, two new PV plants and two wind farms are under construction with a total capacity of around 400MW. After that, we have a highly visible pipeline of projects.*

*We want to demonstrate with our activity that renewables provide the only sustainable solution for energy demand at a global level, and that this represents a huge opportunity for all regions. Chile has, in many occasions, showed its strong climate leadership on decarbonization and carbon neutrality. This report is key to proving that that path is not only environmentally responsible, but also the least-cost option for the country.*

***José Manuel Entrecañales***

***Chairman & CEO, ACCIONA***

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## Section 1. Executive summary

### 67%

Wind and solar generation in Chile in 2050

### 80%

Fall in emissions by 2050

### \$35 billion

Total investment in new generating capacity (USD)

Over the past decade, Chile has begun a rapid shift toward cleaner energy, aided by a liberalized power market and strong policy support. In the next three decades, the country's electricity system is expected to be transformed further, with lower- and lower-cost renewable resources gradually pushing out conventional power plants. Chile has high renewables potential, but has already begun to experience the challenges associated with increasing penetration of variable clean energy sources. In this report, we model a long-term outlook for the energy system, as well as an accelerated de-carbonization scenario, to explore how Chile's power system may adapt to increasing volumes of solar and wind.

This report is written by BloombergNEF in partnership with ACCIONA. It combines BNEF's proprietary New Energy Outlook modelling tools with ACCIONA's detailed understanding of the Chilean market to produce an economic forecast for the energy system, as well as a scenario in which coal is phased out by 2040. The latter scenario, an explicit goal of the country, is a variant of the base case, and explores the implications of the policy across a rapidly evolving electricity system. The report's main conclusions are:

- **Chile's world-class renewable resources mean wind and solar will play a key role in its energy mix.** These technologies steadily push conventional plants out of the system, cutting reliance on coal, gas and oil generation. From a 13% combined share of generation today, wind and solar surge, to supply 40% of generation by 2030; by 2050 they produce two thirds of Chile's electricity.
- **Utility-scale batteries see a large uptake from the mid-2030s,** providing critical flexibility to the system by shifting solar electricity towards the evening peak. Large scale batteries are the main driver of storage growth, replacing back-up generation from oil-fired power and complementing Chile's solar buildout. By 2050, some 13GW of battery storage are installed, and more than the 10GW of fossil fuel generation are retired over the same period.
- **New generating capacity will attract total investment of about \$35 billion,** with 93% going to wind and solar, while storage presents an \$8 billion investment opportunity. A wave of end of life retirements in the 2040s, including coal, gas and oil, drives investments in flexible capacity and renewables, but slowing demand growth means limited investment post-2045.
- **Coal retains a long-term role in Chile's system on an economic basis,** unless there is robust policy intervention. In our base case, its share of generation tumbles from 39% today to 6% by 2050. However, it remains important as the cheapest source of bulk generation to complement variable renewables.
- **Chile's power sector emissions have already peaked,** in 2016. Increased generation from solar and wind, in combination with batteries, steadily erode the need for bulk coal power. This gradually reduces emissions from 41MtCO<sub>2</sub> today, stabilizing just below 10MtCO<sub>2</sub> by



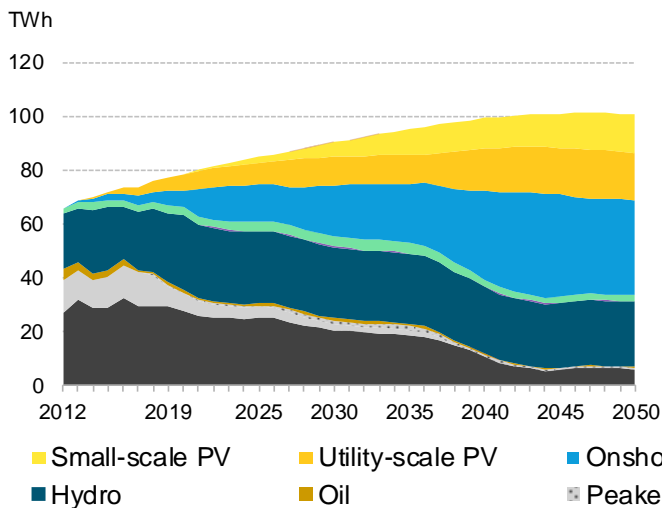
the early 2040s. That represents a reduction of more than 80%, even as electricity demand rises by 33% in the same period.

- **Behind-the-meter generation is expected to see growth** driven by strong consumer uptake. Consumer adoption dynamics, strong solar irradiation, and the economic incentive offered by electricity retail tariffs combine to drive rooftop solar beginning at the end of the next decade.
- **If implemented, complete retirement of the coal fleet brings more wind and storage** capacity online and earlier. Wind and storage replace some of the bulk and back-up generation, respectively, that is provided by coal and offer flexibility in a power system with even higher renewables penetration. Emissions end up 75% lower compared to the base case, but total investment needed is over \$10 billion (25%) higher.

**Table 1: Summary of scenario outcomes, 2050**

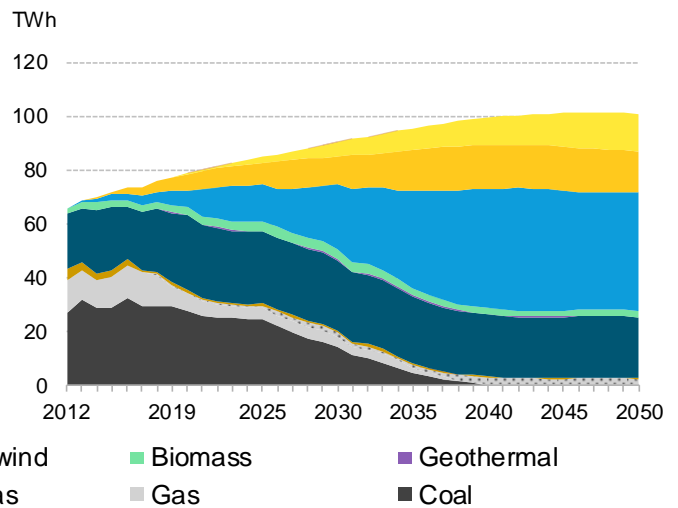
Scenario	Total investments in new generation and flexible capacity (USD)	Emissions	Fossil capacity	Variable renewable share of generation	Renewable share of generation
Base case	\$42.4 bn	8MtCO2	7GW	67%	93%
Coal phase-out	\$53.2 bn	2MtCO2	6GW	73%	98%

**Figure 1: Chile generation mix: base case**



Source: BloombergNEF

**Figure 2: Chile generation mix: coal phase-out**



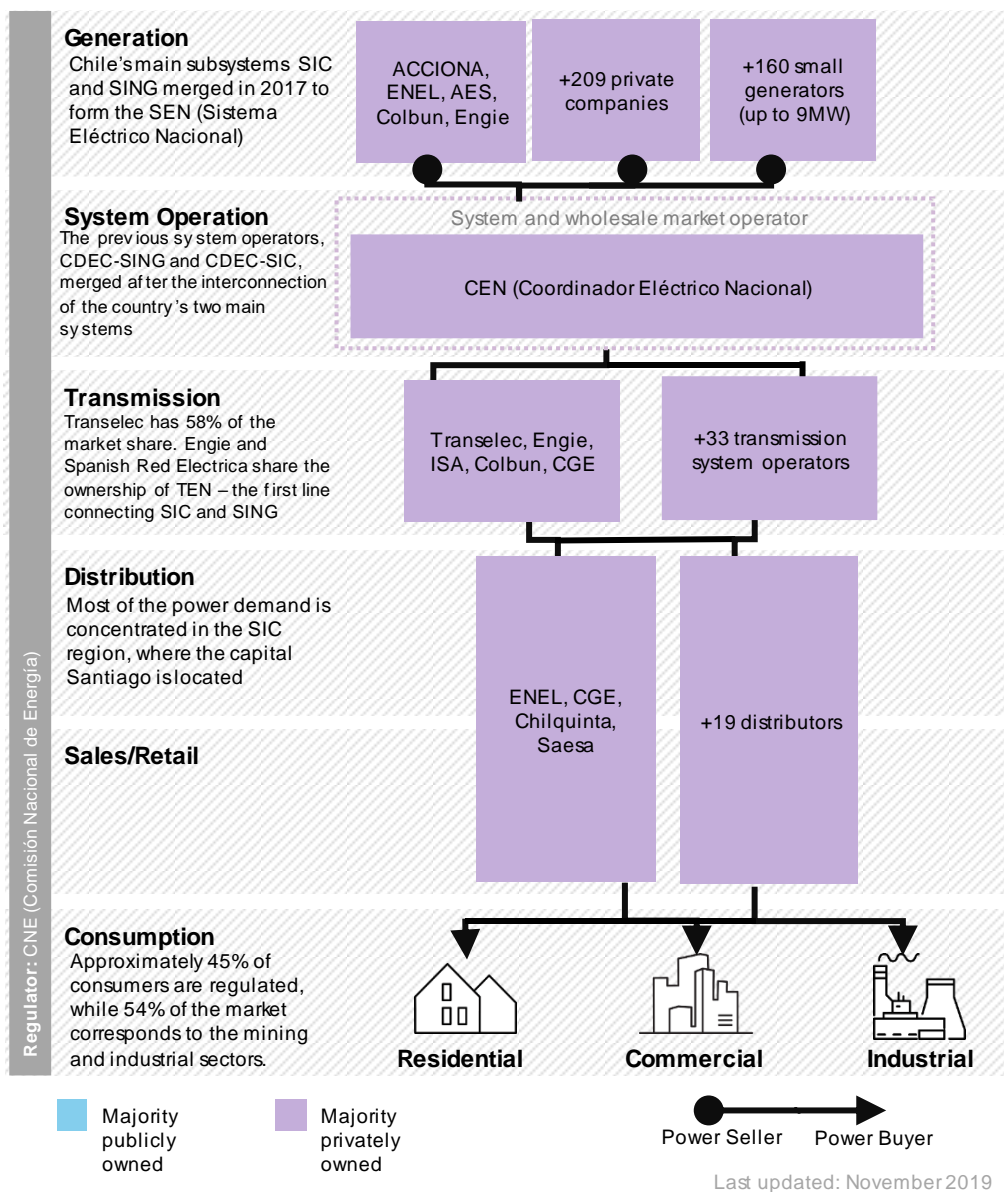
Source: BloombergNEF

## Section 2. Retrospective analysis

### Overview

Chile's economy has benefited in recent decades from growing exports of copper, wood pulp, fish, and wine. Beyond its exportable commodities, Chile has over the last decade begun to capitalize on other domestic resources, namely gusty coastal winds, strong desert sun, and plate tectonic conditions that have made geothermal power-generation viable in some areas.

Figure 3: Chile power sector structure



Source: BloombergNEF. Note: The SIC and SING systems were interconnected in November 2017.

A rapid shift away from fossil sources of power generation toward cleaner energy has been aided by the presence of a liberalized power market and strong policy support for non-large hydro renewables. Recent additions of new renewables in Chile have, in fact, been so substantial that they have created new challenges. The build-out's unintended impacts have included deeply depressed power prices and curtailment in some regions. The country has taken important steps to resolve these issues.

### Power sector structure

Chile's power sector has been de-regulated since the 1980s. It invites private investment at multiple points along its value chain, including generation, transmission, and distribution. Participants have included many international power generators, either directly or via various partnerships and joint ventures. Well over 100 corporate entities have been involved with owning power-generating assets. Transmission, distribution, and sales and retail services similarly are controlled by private players.

Chile historically had two major power grids (and two very minor ones) reflecting the vertical orientation of the country, which runs 4,300km (2,700 miles) from north to south (Figure 4). Over 90% of the population was traditionally served by the *Sistema Interconectado Central* (SIC) while the *Sistema Interconectado del Norte Grande* (SING) was critical in servicing the country's mining operations in northern part of the country.

The Atacama Desert in the north receives some of the strongest, most consistent sunshine on Earth and has seen substantial solar project development. The SING is home to a quarter of the country's total generating capacity, largely serving mining operations in the region. For decades, the SIC and SING operated independent of one another. That changed in November 2017 when a new, \$700-million interconnection was completed. Among its goals was to ease delivery of low-cost clean energy from the remote desert to population centers further south. The interconnection was reinforced with the commissioning of the 753km Polpaico-Cardones line in mid-2019. This has further alleviated grid congestion.

Figure 4: Chile's power systems



Source: CNE

Figure 5: Chile installed capacity, 2018

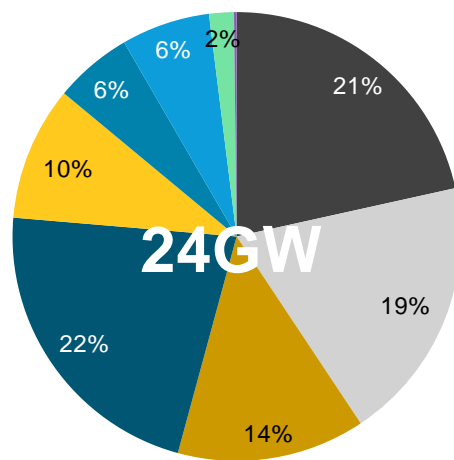
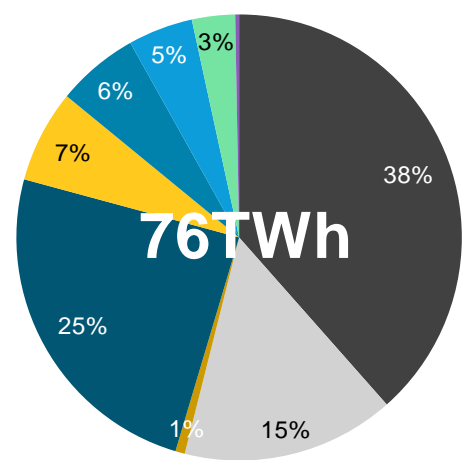


Figure 6: Chile power generation, 2018



■ Coal ■ Gas ■ Oil ■ Large hydro ■ PV ■ Small hydro ■ Wind onshore ■ Biomass & waste ■ Geothermal

Source: CNE, BloombergNEF, Climatescope



In addition to sun, Chile has exceptional resources to support projects. Today, solar, wind, geothermal, biomass, and small hydro account for 24% of the country’s capacity and 21% of generation (Figure 5 and Figure 6).

Wind and solar together currently provide 13% of Chile power generation, while the single largest source of supply remains coal at 38%. Thermal assets represent 54% of Chile’s 24GW fleet, while clean energy accounts for 24% (Figure 7 and Figure 8).

Figure 7: Chile generation by technology

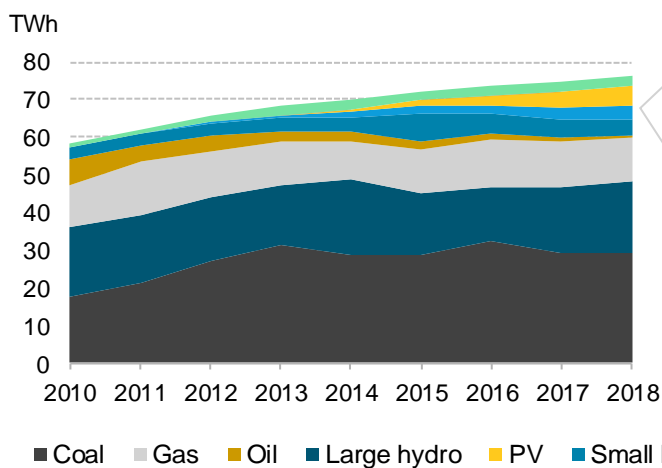
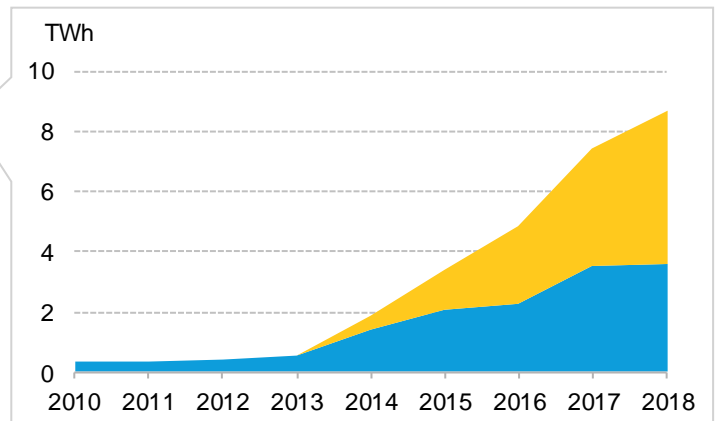


Figure 8: Chile generation from wind and solar



■ Coal ■ Gas ■ Oil ■ Large hydro ■ PV ■ Small hydro ■ Wind onshore ■ Biomass & waste ■ Geothermal

Source: CNE, BloombergNEF, Climatescope

### Policies

Chile has added virtually all of its non-hydro renewable capacity in the past six years. That build-out has been spurred by concerted policy support from the national government starting in 2013 with the amendment of Law No. 20.527 and the requirement that utilities with up to 200MW of operational capacity meet 20% of their contractual obligations with renewable sources by 2025. The amendment marked a substantial increase from the goal of 10% by 2024 that Chile first set for itself in 2008.

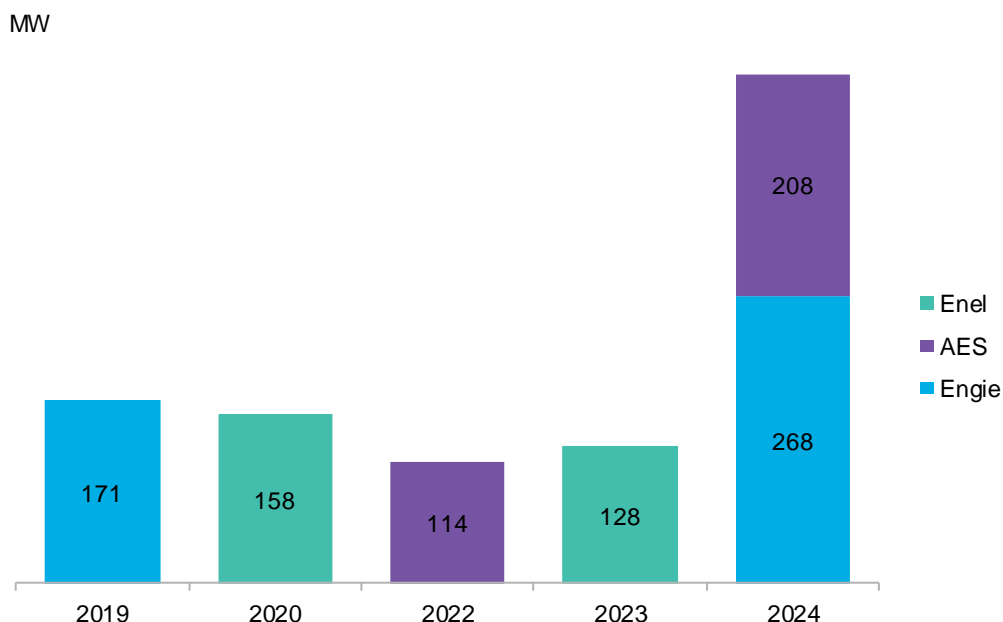
The raising of the quota was well timed as clean energy equipment prices were just beginning a precipitous decline that has continued to today. Beyond merely setting a goal, the government followed through with specific policies to promote clean energy’s growth. Most notable among these were:

- **Tenders to secure clean power-delivery contracts.** Chile has organized reverse auctions to procure power from various sources since 2006. But only in 2014 did the government create a tender mechanism tailored to wind and solar developers’ needs. Under the new scheme, generators compete in auctions to supply power during specific periods of the day or “time blocks”. This change served to improve the competitiveness of intermittent sources such as wind and solar by allowing their developers to bid most aggressively for the blocks when they could best serve the market. Such tenders have been technology-blind, meaning renewables have competed directly with fossil sources of generation. As wind and, in particular, solar costs fell, those technologies became increasingly competitive.
- **Net billing to promote distributed generation.** In October 2014, Chile began allowing those with localized, distributed power-generating capacity such as rooftop PV systems to “sell”

their excess generation back to their utility at the retail rate by receiving compensating discounts on their bills. In cases where generation in a given month from a distributed system exceeds the amount a customer receives from the grid, credits can be rolled into the following month's bill. The program is similar to "net metering" schemes in some U.S. states and elsewhere around the world. On 17 November 2018, the net billing law was updated, expanding the size limit for installations from 100kW to 300kW.

- Coal moratorium.** In June 2019, Chile unveiled a plan to retire all of its 5GW of coal-fired capacity by 2040, as well as a schedule to retire the first 1GW by 2024 (see Figure 9). The move made Chile the first South American nation officially to declare a coal moratorium. The same week, two plants closed, marking the first step toward phase one's goal of shuttering eight stations owned by Engie, AES, and Enel in five years. Earlier in the year, Engie commissioned a 375MW coal plant. However, all coal power plant owners, including AES Gener, Colbún, Enel and Engie, have committed not to invest in new projects.

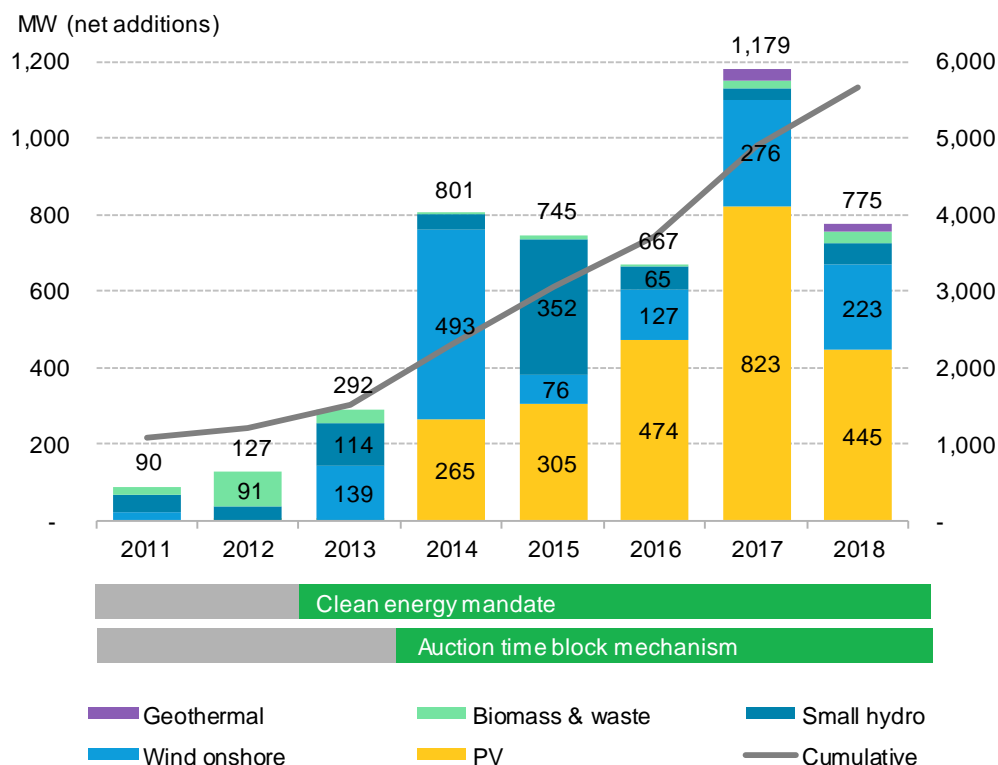
**Figure 9: Chile's 2024 coal retirement schedule, by company commitment**



Source: Chile's Energy Ministry, BloombergNEF

- A carbon tax to make fossil generation less competitive.** Law 20.780, passed in 2014, established for the first time a levy on CO2 emissions. The regulation, which went into effect in 2017, requires owners of power plants 50MW or larger to pay \$5 per metric ton of CO2 emissions. The effectiveness of the carbon tax is limited, however, as it is not taken into account in determining dispatch, preserving the position of coal generators in the merit order.

Figure 10: Chile renewable energy capacity net additions, 2012-2018



Source: CNE, BloombergNEF

Nearly all Chile’s current wind and PV capacity has been built since these policies were put in motion with the law supporting tenders playing a particularly critical role in supporting utility-scale projects. From 2014 through November 2019, Chile brought online 1.6GW of wind and 2.8GW of PV to become Latin America’s third largest clean energy market (Figure 10).

In the first tender, held in 2014, renewables projects won contracts to deliver just 7% of the generation up for contract. The contribution of renewables rose in the ensuing two auctions as the average price of the contracts slipped. In two of the last three tenders held, renewables have accounted for 100% of all generation up for contract.

The goal of the tenders was to tap market forces to get the lowest possible bids for clean energy. They appear to have had their intended effect. A tender held in 2016 produced an average weighted bid price of \$45/MWh for wind and \$29/MWh for solar. Another reverse auction held in 2017 saw the average winning wind bid sink to \$36/MWh and the equivalent for solar fall to just \$25/MWh. The auction also included a contract-winning PV project in the Atacama Region, its developer promising to deliver power at an incredibly low \$21.5/MWh.

### Rising renewable energy penetration, falling power prices

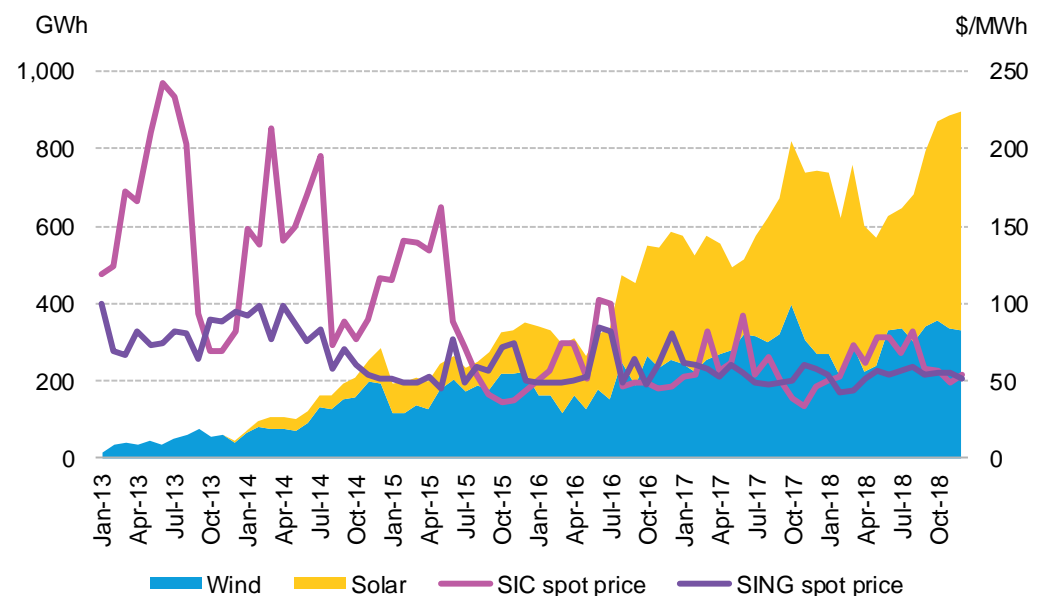
Despite better insolation and wind resources in the SING, where the Atacama Desert is located, SIC hosts 90% of wind and 72% of solar commissioned projects in Chile. Developers have often opted to build in the SIC because it is home to most retail power demand but still offers exceptional solar resources at the northern end of its grid. Only in November 2017 were the SIC and SING physically connected for the first time, via the 600-km TEN line. In June 2019, Chile

commissioned the second high-voltage transmission line connecting the two systems, the 753-km Cardones-Polpaico line.

Because they have no associated fuel costs, solar and wind projects essentially operate as zero marginal-cost generators in Chile’s liberalized power market. Provided demand exists, these projects generate and sell their power onto the system regardless of the price. By producing for least cost, they pull down the overall market-clearing price for all generators.

Chile has numerous nodes where power gets bought and sold and no single benchmark hub price. The nodes Quillota and Crucero are used as a reference to determine spot price for SIC and SING. Between 2014 and 2018, wind and solar generation grew by 153% and 1016%, respectively, throughout the country. The impact of clean and cheap energy on the market is clear. During the same period, SIC and SING spot prices fell by 52% and 30%, respectively (Figure 11).

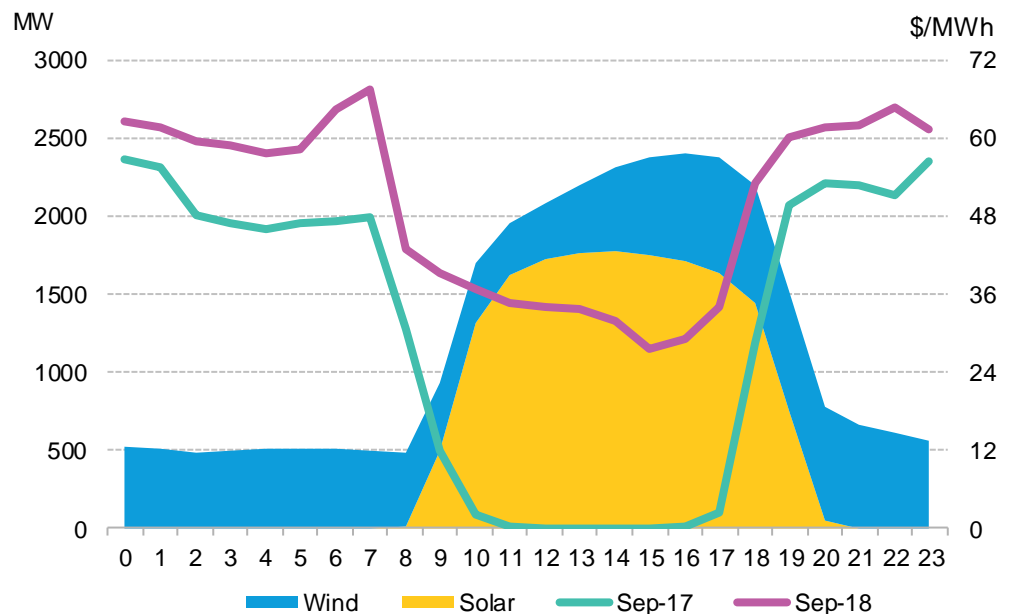
**Figure 11: Chile wind and solar generation (GWh) versus SIC and SING spot prices (\$/MWh)**



Source: CNE, CEN, BloombergNEF

Before the interconnection, spot prices in Chile’s wholesale market experienced significant volatility. In September 2017, for instance, the spot price at the Diego de Almagro node averaged \$0/MWh between 11am and 4pm each day. While prices climbed during the nighttime hours, that offered little comfort to owners of PV projects who generate during daytime hours alone. After the commissioning of the first line interconnecting the two systems in November 2017, average prices in September 2018 increased significantly in that node, providing some relief for clean energy assets. (Figure 12). The improvement in pricing and reduced congestion underscore the critical role transmission plays in the context of rapid renewable energy penetration.

**Figure 12: Chile National Electricity System (SEN) hourly wind and solar generation versus Diego de Almagro spot price, September 2017 and 2018**



Source: CNE, CEN, BloombergNEF. Note: Wind and solar generation, monthly average September 2018. Average spot price of Diego de Almagro node in September 2017 and September 2018.

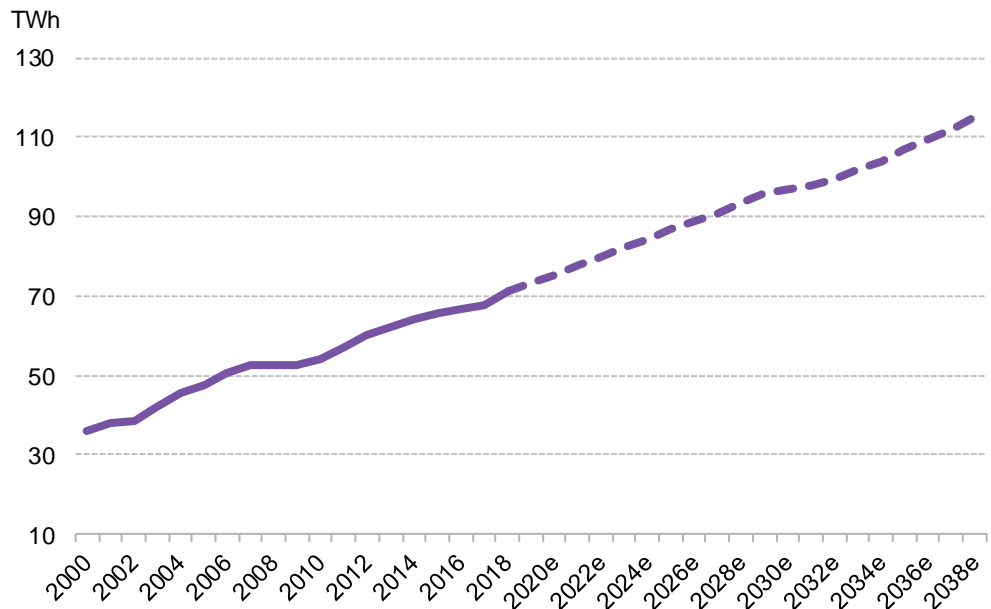
Both "merchant" projects that seek to sell all their power at spot prices and those with signed long-term power-purchase agreements, or PPAs, are exposed to wholesale price volatility risk in Chile. For the latter, this is because all power that a project generates must first be sold at the node where it connects to the grid, then be bought back by that same generator at the node nearest to where the offtaker has contracted to receive it. The original producer then sells the power to the offtaker at the pre-agreed PPA price.

### Disappointing economic growth and the role of copper

Chile's GDP grew in real terms by 6% per year during each of the first few years of this decade and policy-makers had expected that continued strong economic growth would require substantial new power-generating capacity. However, the economy fell short of expectations over the period 2014-17, growing at approximately 2% annually in real terms, before posting strong 4% growth in 2018. Growth is forecast to hit 2.2% in 2019.

For its part, the energy regulator's predictions for electricity demand growth have proven overly optimistic. At the start of each year since 2014, the Comisión Nacional de la Energía (CNE) has forecast future Chile power demand. In 2015, CNE forecast an average of 3.9% per year in electricity demand growth through 2030. In 2016, the agency lowered that to 3.5%. In 2017, it reduced it again, to 2.7%. In 2018, it fell to 2.4% for the period through 2038. (Figure 13).



**Figure 13: Chile National Electricity System (SEN) demand forecast**

Source: CNE's 2018-2038 National Electricity System (SEN) demand forecast, July 2019. Note: The long term outlook is based on BNEF's projected peak and total demand.

Chile's export-reliant economy has felt the pinch as global demand for its copper has cooled somewhat. Copper typically accounts for almost half of Chile's exports on a dollar basis and these have weakened due to lower demand from China. Chile's annual copper production hit a peak at 5.8 million tons in 2015 before sliding in subsequent years. The country's mining output resumed growth in 2019, up 5.3% in August from the same month a year earlier, boosted by 7% growth in copper production.

Copper prices rose by about one third in 2017, but they have given back nearly all those gains over 2018-19 (as of mid-November). There is little to suggest the industry will return to strong growth this year. Ongoing trade tensions and civil unrest pose risks. While protests have not significantly impacted copper mine production, Chile's exports of copper dropped by 21% in October. Given that mining, led by copper, accounts for approximately 30% of all power consumed in Chile in a given year, slowing demand for the metal is likely to cap overall electricity consumption growth.

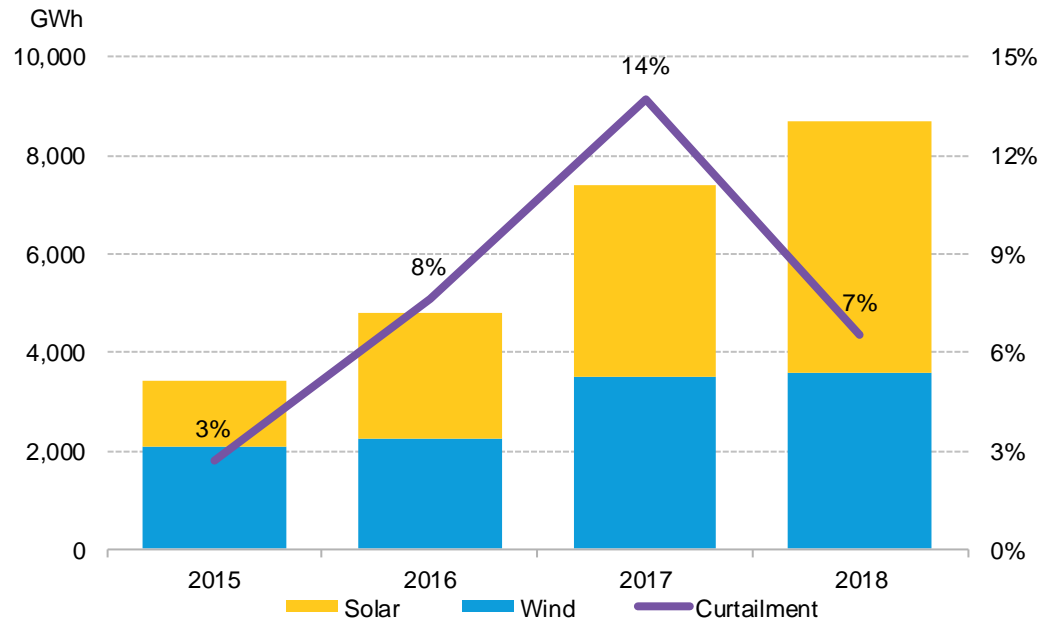
### Curtailment and the push for new transmission

Slower-than-anticipated demand growth coupled with an increase of approximately 50% in new power-generating capacity in the past decade has not just depressed power prices in Chile, it has also caused curtailment of generation for some clean energy projects.

Curtailment first appeared in Chile in August 2015 and had been increasing substantially, hand-in-hand with wind and solar generation. In 2016, some 398GWh, or 8% of total wind and solar generation went unconsumed in Chile. In 2017, that rose to 1,179GWh (14%). Not all that curtailment was driven entirely by economics as some fossil fuel-burning plants received higher dispatch priority in the system to ensure baseload needs were met. Since 2017, the government has been auditing certain thermal plants in an effort to reduce their dispatch requirements. In November 2017, Chile commissioned TEN, the first line interconnecting SIC and SING. As a

consequence, curtailment rates dropped to 7% (609GWh) in 2018, even with clean energy generation growth.

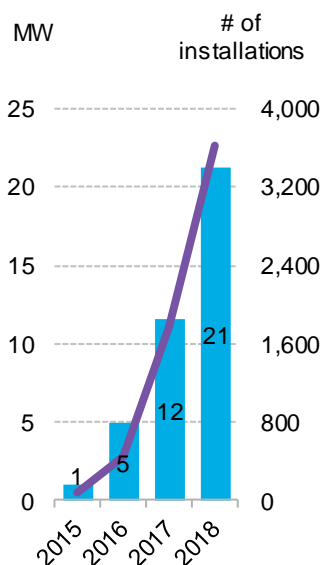
**Figure 14: Annual wind and solar generation versus wind and solar curtailment**



Source: CNE, CEN, BloombergNEF

Lack of adequate transmission remains a challenge in Chile. By the end of 2018, Chile had 32,184km of transmission lines, virtually unchanged from the previous two years. In April 2019, Chile opened a tender to build two new lines and other supporting transmission projects. The system operator, Coordinador Eléctrico Nacional (CEN), received offers in November and plans to reveal results by February 2020.

**Figure 15: Small-scale PV installations**



Source: CNE

Chile achieved a milestone for its power market in June 2019 by commissioning a second transmission line connecting its main power grids, the SIC and SING. The 1,700MW Cardones-Polpaico line was operating at full capacity three months after being inaugurated. The interconnection is critical for integration of clean power produced in the north of the country with demand located in the central region.

### The role of distributed energy

Chile has had supportive net billing rules since 2014 to encourage small-scale distributed energy power generation. Over the past four years, the country has seen a total of 3,611 small PV systems come online, totalling 21.1MW of installed capacity (Figure 15). The cumulative capacity quadrupled from 2015 to 2016 then nearly doubled from 2016 to 2017 and again from 2017 to 2018. The country's exceptionally strong sun combined with residential power prices make small-scale PV quite appealing to many consumers – provided they have the financial resources to install such systems.

In October 2019, the Ministry of Energy, Ministry of Environment and public bank BancoEstado launched a credit line specifically dedicated to finance residential PV systems at a 0.52% monthly rate. The line is also available for residential energy efficiency projects. The government estimates that a house with rooftop PV could lower its electricity bill significantly.

Chile also offers its Pequeños Medios de Generación Distribuida (PMGD) mechanism to support the development of somewhat larger distributed energy projects. PMGD allows projects with capacity below 9MW to sell into the spot market using a stabilized price fixed by CNE and published every six months.

Compared to projects with signed, long-term PPAs that are exposed to price risk, the PMGD scheme offers significant stability. It is a relatively low-risk option for smaller projects to avoid selling power in the wholesale market where they can be exposed to spot price fluctuations.

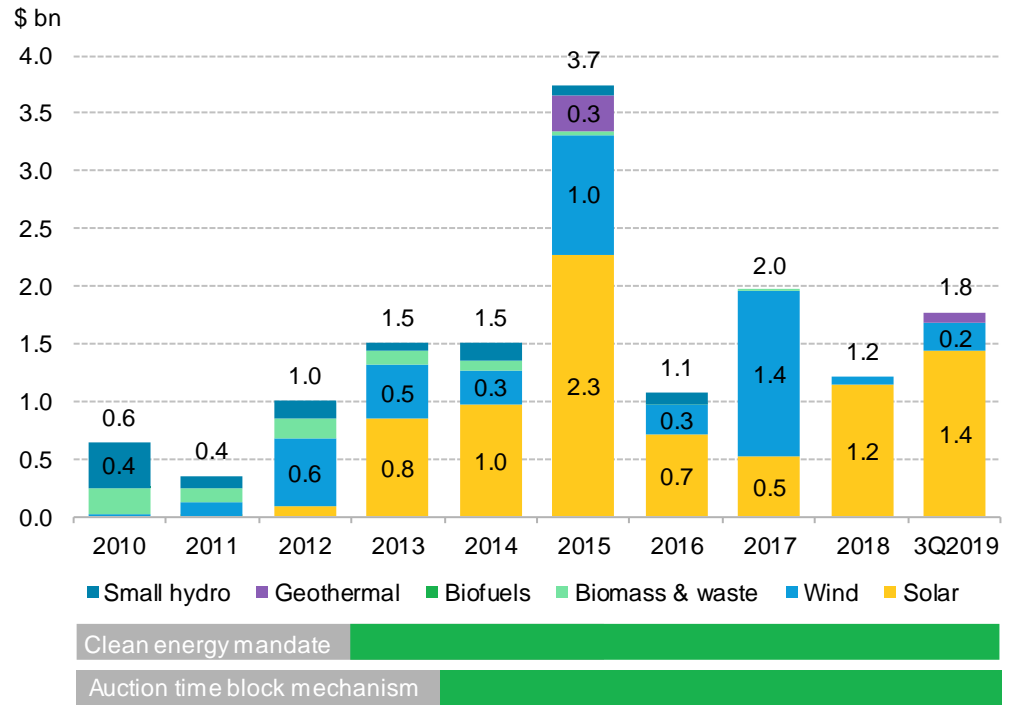
Since it was introduced in September 2014, some 746MW of clean energy capacity has been installed under the PMGD, or 13% of all renewable capacity added over this period. The boom of additions under the scheme reflects the volatility in spot prices and high competition in auctions. Projects subject to the stabilized price scheme have already been financed by multilateral lenders and Chilean commercial banks, setting a precedent in the country's energy market and confirming PMGD projects as a viable, alternative option for developers and investors.

However, since October 2019, the Energy Ministry has been reviewing regulations that govern the policy. The proposal is focused on changing the methodology to one in which the price paid would be defined according to time blocks during the day. The modification would penalize renewable energy projects, and solar in particular, as prices can approach zero at some hours. A final decision is pending government approval.

## 2.1. Clean energy investment

Chile has attracted a cumulative \$14.8 billion in investment in large-scale renewable power projects since the start of 2010, with the country being one of the hottest clean energy markets in the world at times during that period (Figure 16). In 2019, Chile ranked second in [Climatescope](#), a survey of developing nations BloombergNEF conducts annually with support from the UK Department for International Development after having placed first in 2018. This reflects the country's overall attractiveness for foreign investment in clean energy. In particular, Chile has built a strong enabling framework as defined by a series of effective policies and relative overall economic stability. It is also home to a more significant manufacturing value chain for clean energy components than many other developing countries.

**Figure 16: Chile new-build clean energy investment by sector**



Source: BloombergNEF

Investment in Chile clean energy peaked in 2015 at nearly \$3.7 billion. Investment in new capacity slowed down after 2015, but the outlook for the next years is positive as a number of companies have revealed big plans. ACCIONA has two new PV plants and two wind farms under construction with a total capacity of around 400 MW, to be followed by a large pipeline of projects. Together with other companies, large investments aimed at bringing several gigawatts of wind and solar assets online cumulatively have been announced.

## Section 3. Long-term outlook

Our long-term outlook for Chile's electricity system focuses on technologies that are driving change in markets and business models, including solar PV, wind and storage. In addition, we highlight changing electricity demand and the growing role of consumers. Over the past decade, Chile has begun a rapid shift toward cleaner energy. In the next three decades, the country's electricity system is expected to be transformed further, with lower- and lower-cost renewable resources gradually pushing out conventional power plants. We model a long-term outlook for Chile's energy system, as well as an accelerated de-carbonization scenario in which coal is phased out by 2040, to explore how it may adapt to increasing volumes of solar and wind.

### 3.1. Methodology

In the near term, we make market projections based on an assessment of policy-drivers, and on BloombergNEF's proprietary project database, which provides detailed insight into new power plant development, retrofits and retirements, by country and sector. For the medium to long term, our results emerge from a least-cost optimization exercise, driven by the cost of building different power generation technologies to meet projected peak and total demand, which may differ from official forecasts, taking into account seasonal weather extremes. We model small-scale and large-scale battery systems, as well as taking a view on the growth of time-of-use load shifting, dispatchable demand turn-down, and the charging of electric vehicles. These new sources of flexibility allow for more dynamic balancing of supply and demand, and become particularly important in markets where large amounts of variable wind and solar are deployed and conventional assets retire.

This analysis does not take into account long-term international climate targets, such as the Paris Agreement, nor do we incorporate proposals for national energy policies or targets unless a mechanism to ensure compliance has been put into law. We do include carbon prices where they already exist, and where they are in late stages of development and we have high confidence they will emerge in the near term. We capture all existing policies, but are quick to remove them once they have run their course. As with our global New Energy Outlook, or NEO, the projection for Chile in this report is market-agnostic, concerned only with achieving a lowest system-cost result, and does not take a view on price formation. Issues related to the nodal structure of Chile's system have not been modelled and the real time operation of the system is not covered in the study. All figures are in U.S. dollars. For more details on modelling methodology, see BloombergNEF's 2019 New Energy Outlook.

The coal phase-out scenario is based on Chile's stated intention to retire its entire coal-fired power station fleet by 2040. The country has already revealed the first phase of its plan. According to this, some 1GW of coal assets are expected to be retired by 2024, taking one fifth of its coal offline in five years. The government has not disclosed next steps, so this secondary scenario assumes a linear retirement of coal assets in five-year increments by plant age.



### 3.2. Summary

Chile's electricity system meets steady demand growth over the next 30 years almost exclusively through expanded use of inexpensive renewable and natural gas resources. Current cost competitiveness for wind and solar ensures they are the cheapest forms of new generation in the near term and account for the lion's share of build over the 30-year period. From a 13% share today, wind and solar grow to supply 40% of generation by 2030; by 2050 they produce two-thirds of Chile's electricity. These technologies steadily push conventional plants out of the system, reducing reliance on fossil fuel generation.

The role of the country's maturing coal fleet is steadily diminished in the coming decades, its share of generation halving from 40% today to under 20% by the mid-2030s. However, Chile's high penetration of variable resources means coal and natural gas plants retain an important role in meeting baseload, as well as peak-load, requirements. Without policy intervention, coal would retain a role in the system in 2050, representing 6% of the generation mix. Batteries begin making a clear impact from the mid-2030s, complementing Chile's solar buildout and providing critical flexibility to the system by shifting solar electricity towards the evening peak. CO2 emissions from the power sector fall over 80% by 2050 from today's levels, even as demand rises by 33% in the same period.

**Table 2: Key messages**

Key messages	
1	Chile's world-class renewable resources mean wind and solar will play a key role in its energy mix. These technologies steadily push conventional plants out of the system, cutting reliance on coal, gas and oil.
2	Utility-scale batteries see a large uptake from the mid-2030s, providing critical flexibility to the system by shifting solar electricity towards the evening peak.
3	New generating capacity will attract total investment of about \$35 billion, with 93% going to wind and solar, while storage presents an \$8 billion investment opportunity.
4	Coal retains a long-term role in Chile's system on an economic basis, unless there is robust policy intervention.
5	Chile's power sector emissions have already peaked, in 2016. Increased generation from solar and wind, in combination with batteries, steadily erode the need for bulk coal power.
6	Behind-the-meter generation is expected to see future growth driven by strong consumer uptake.
7	If implemented, complete retirement of the coal fleet brings more wind and storage capacity online and earlier, reducing emissions but raising total investment needs.

Source: BloombergNEF

### 3.3. Key messages

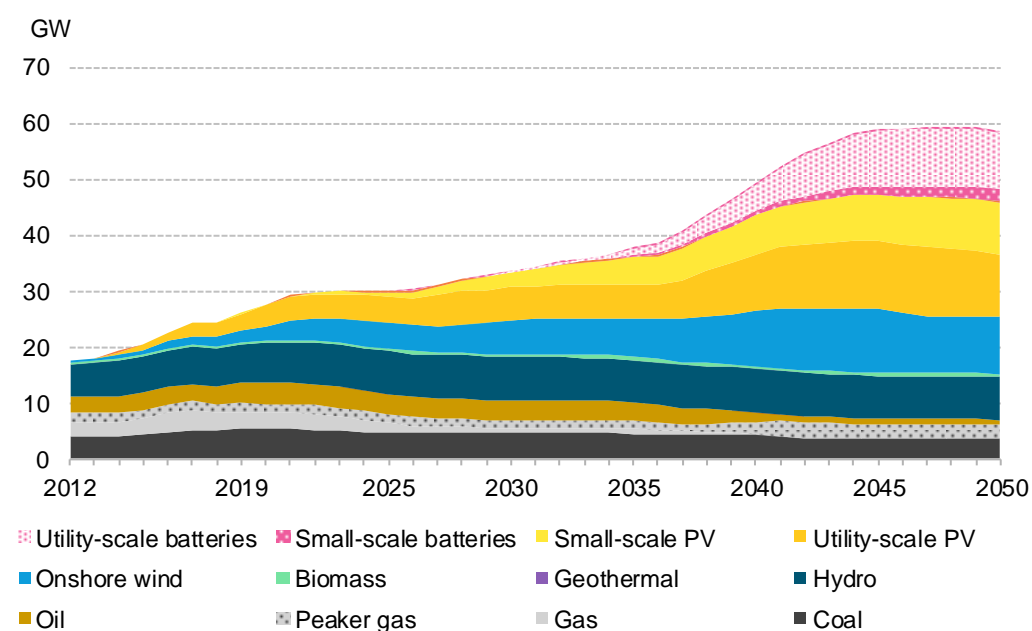
#### 1. Chile's world-class renewable resources mean wind and solar will play a key role in its energy mix. These technologies steadily push conventional plants out of the system, cutting reliance on coal, gas and oil.

From 2019 to 2050, Chile's power system more than doubles in size, from 24GW to 59GW installed capacity (see Figure 17). Significant build-out occurs over the next decade, with more than 8GW added on a net basis, followed by a second, more dramatic boom in new additions in the late 2030s. Today, Chile is heavily reliant on fossil fuels, with coal, gas and oil accounting for 5.2GW, 4.6GW, and 3.2GW respectively. The need for firm capacity keeps these technologies in the mix in the long term, though they decline steadily as a share of total capacity.

Current dispatchable capacity, both hydro and thermal, accommodates rapid renewable penetration until 2035. Beyond that, growth of flexible capacity including batteries accelerates, becoming an essential component of the system. Excellent solar resources and cheap wind gradually push out conventional power plants. Today, solar and wind account for 4GW of installed capacity. That doubles by 2022 to more than 8GW, and doubles again by 2033. By 2050, these two technologies account for 20GW of installed capacity.

In the coming years utility-scale PV expands rapidly, while small-scale doesn't take off until the second half of the 2020s. Wind capacity grows steadily up to 2045 before levelling off. PV growth is facilitated by the backup provided by batteries, which eventually represent 21% of total capacity. Declining costs for batteries mean they increasingly support PV deployment from 2030 onwards, going hand-in-hand until the installed capacity of both level off in 2045.

**Figure 17: Evolution of Chile generation capacity**



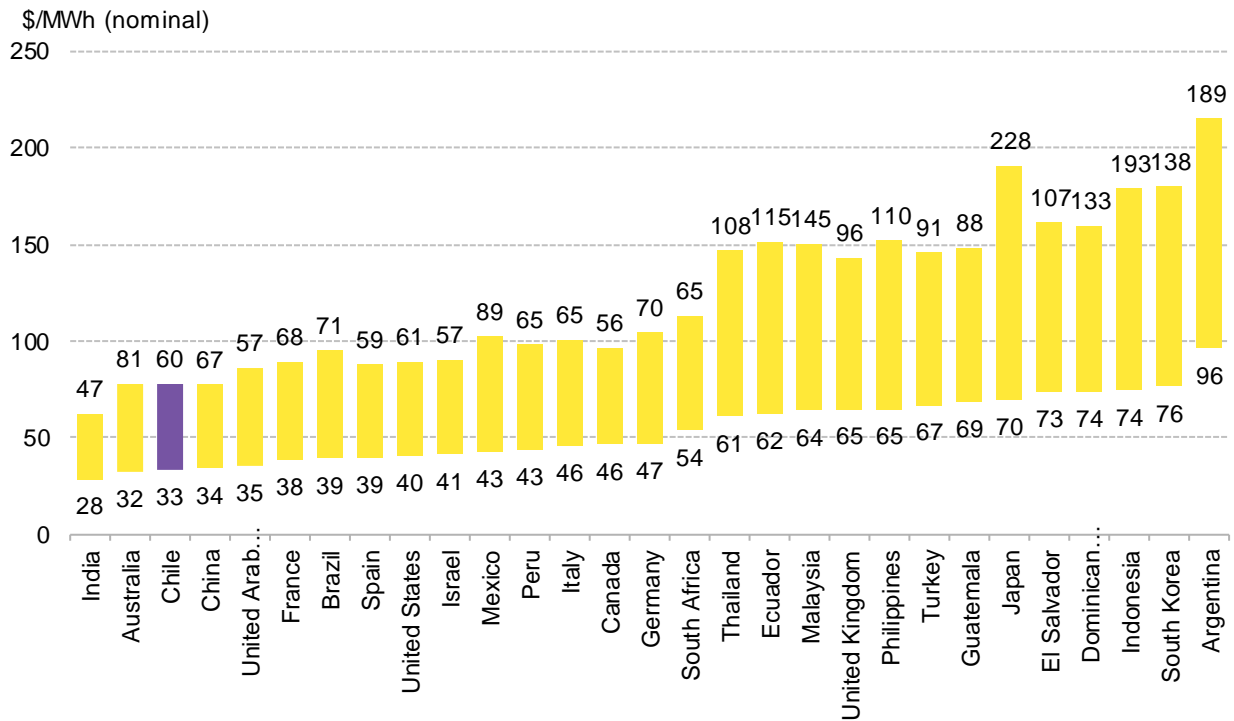
Source: BloombergNEF

Chile's excellent renewable resources are best illustrated by its solar irradiation. According to BloombergNEF's most recent 2019 H2 Levelized Cost of Electricity (LCOE) report, Chile offers

the highest solar capacity factors in the world (20% to 26% DC for fixed-axis panels) and a range of 38-45% for wind. Global benchmark capacity factors average 16% and 31% for solar and wind. These exceptional figures translate into highly competitive LCOEs, a key measure of the cost competitiveness of different power-generating and energy storage technologies.

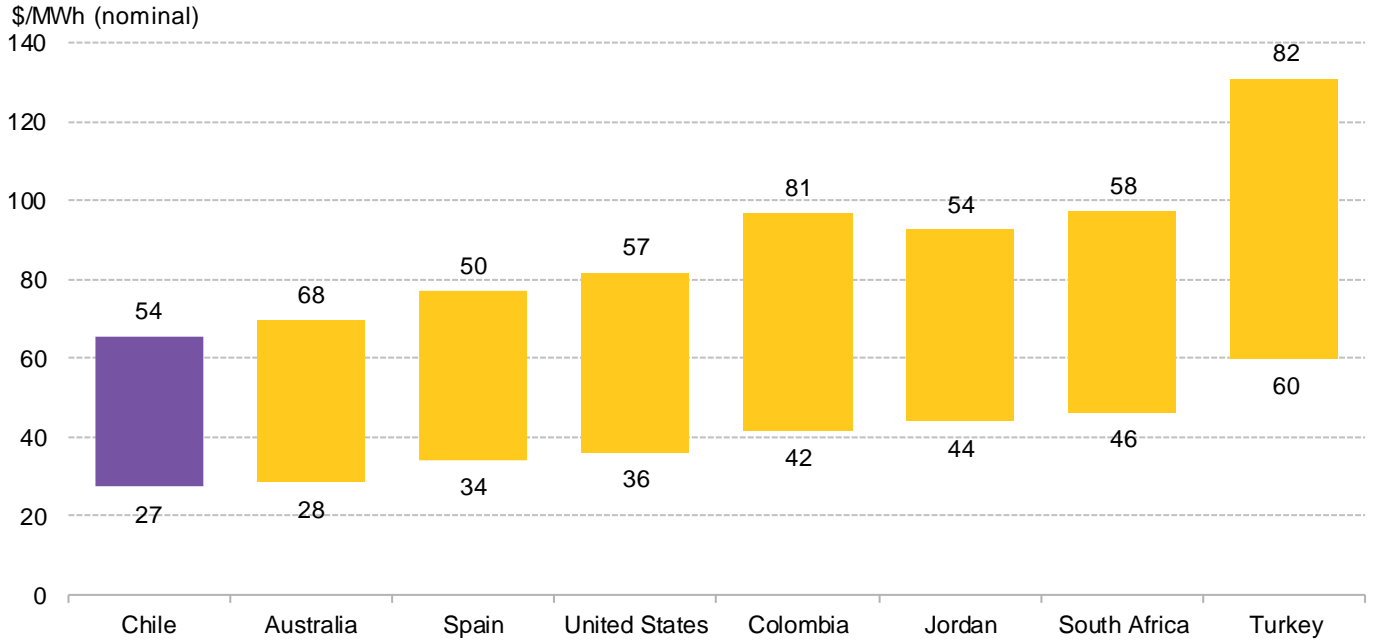
We estimate that some of the cheapest PV projects financed in the last six months will achieve an LCOE of \$27-36/MWh, assuming competitive returns to their equity investors. Chile is among the few places in the world where these figures can be recorded. For PV non-tracking projects in Chile financed in the last six months, the LCOE range is estimated to be \$33-60/MWh, with those with tracking in the range of \$27-54/MWh. We estimate wind projects in Chile financed in the last six months will achieve an LCOE of \$38-58/MWh (Figures 18, 19 and 20).

Figure 18: Current LCOE range (\$/MWh, nominal) – PV non-tracking, 2019 H2



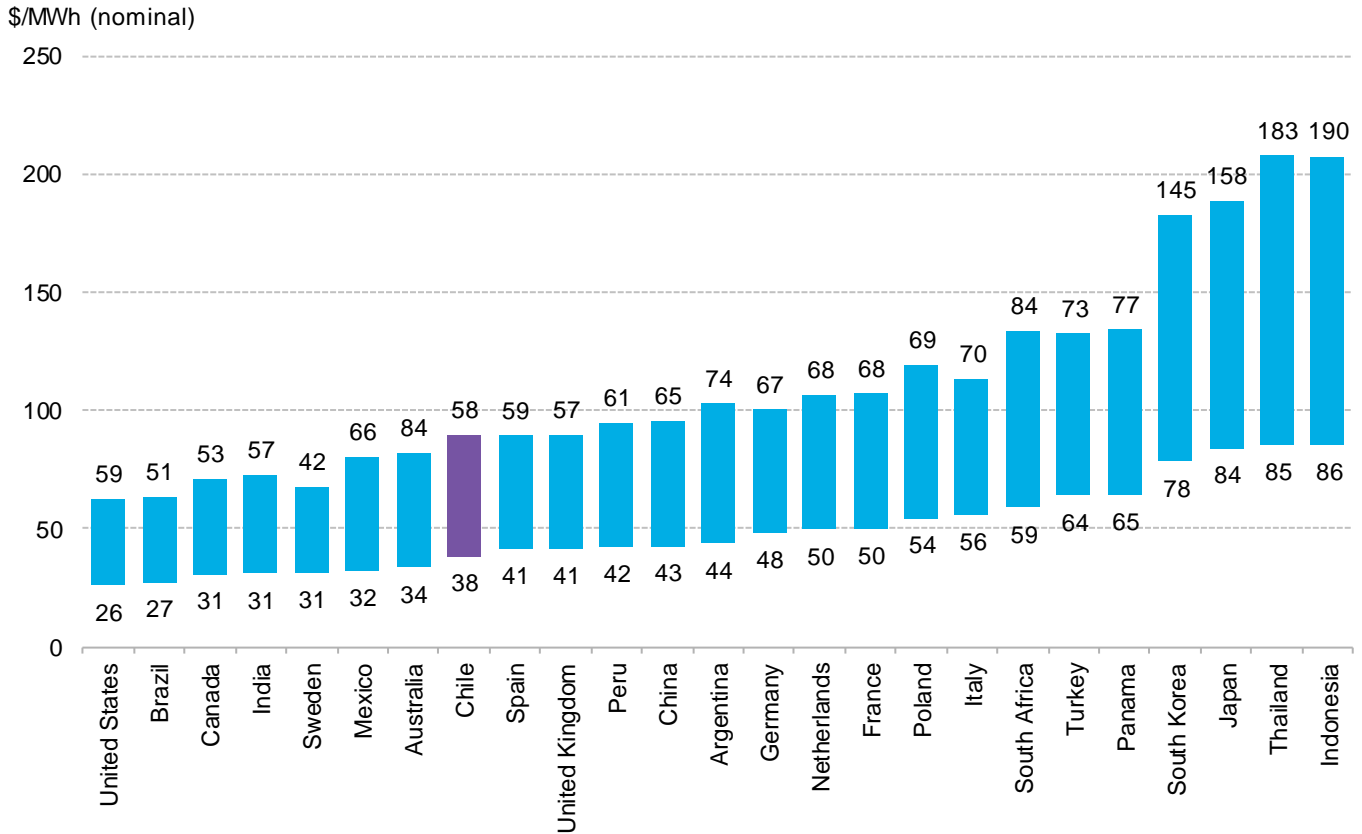
Source: BloombergNEF

Figure 19: Current LCOE range (\$/MWh, nominal) – PV tracking, 2019 H2



Source: BloombergNEF

Figure 20: Current LCOE range (\$/MWh, nominal) – Wind onshore, 2019 H2



Source: BloombergNEF

Utility-scale PV becomes the predominant technology at the end of our outlook (11GW), followed by onshore wind (10GW) and small-scale PV (9GW). From a 13% share of generation today, wind and solar rise to supply 40% of generation by 2030; by 2050 they produce two thirds of Chile’s electricity, thanks to 10GW of wind, 11GW of utility-scale PV and 9GW of small-scale PV. The share of fossil fuel capacity shrinks over time. Today, coal, gas and oil-fired power account for more than half. By 2050, their share drops to 15%, as they mainly provide back-up capacity when the sun is not shining, the wind is not blowing and/or generation from hydro is relatively low.

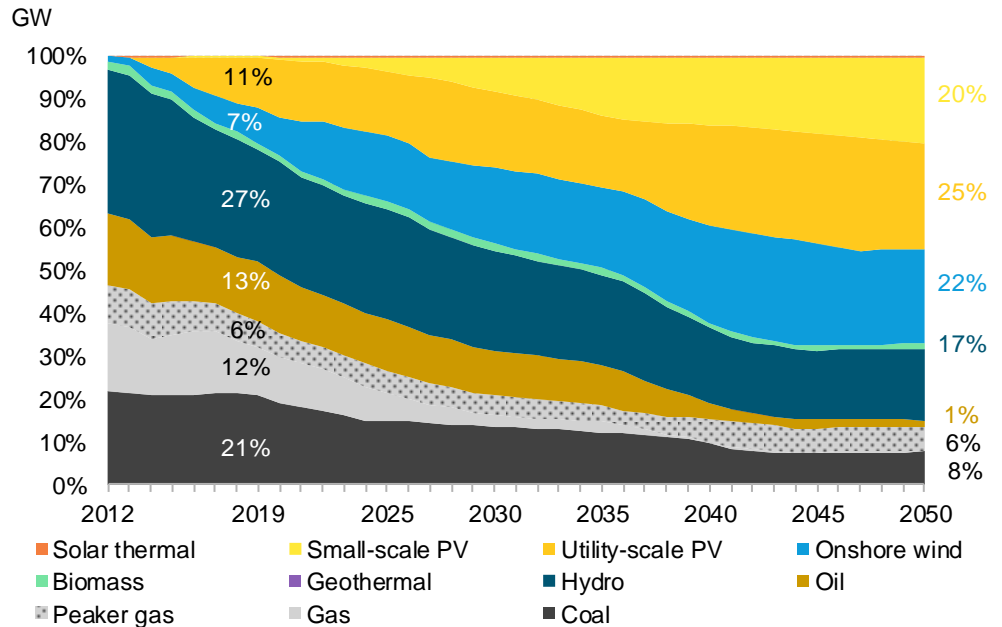
**Chile’s Energy 2050 Roadmap**

In 2016, the Chilean government released the Energy 2050 Roadmap, which lays out long-term plans for the power sector. A key goal for 2050 is for at least 70% of the electricity generated in the country to come from renewable energy sources (including large hydro). Our long-term outlook has this happening by 2030.

Large hydro, an indispensable element of the system today, as well as an important factor in limiting the country’s reliance on thermal generation, fails to grow – for several important reasons specific to the technology. A lack of social license for large hydro plants, environmental concerns, project complexity and site limitations, very long project development lead times and increasing cost competition from wind and PV limit prospects for growth in this study. While hydro still accounts for 17% of the country’s capacity mix by 2050, this is down from more than one quarter today (Figure 21).



Figure 21: Power generating capacity mix

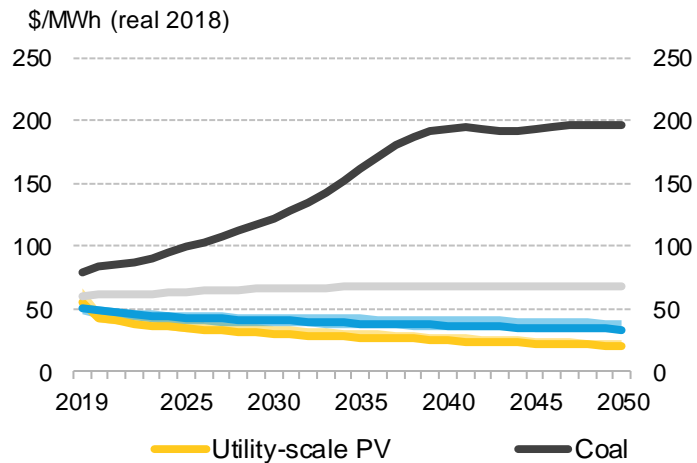


Source: BloombergNEF

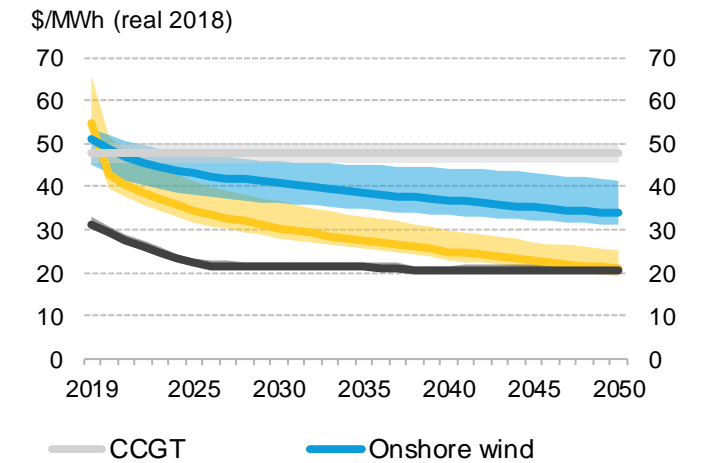
In Chile, ‘tipping point one,’ or the moment when new-build renewable power becomes cheaper than building and operating a new fossil-fuel power plant, has already occurred for both wind and solar (Figure 22). Considering the current cost-competitiveness of solar and wind plants, and their differing cost trajectories compared to new fossil fuel plants, we don’t anticipate that coal and gas can be competitive options for new bulk generation in the country. Rather, the need for bulk generation, whether this arises from growing power demand or offsetting end-of-life retirements, will be met by new solar and wind plants. New gas plants, at best, can play the role of flexibility providers, complementing cheap variable generation from renewables.

The second tipping point occurs when it gets cheaper to build new onshore wind or solar PV than to run an existing coal or gas plant that provides bulk electricity. Once the LCOE of solar or wind falls below the short-run marginal cost of an existing fossil fuel plant, it makes economic sense to replace it with a new unit of renewables capacity, if it is not needed to ensure security of supply. In Chile today, both new solar and onshore wind are reaching parity with existing gas turbines. However, new renewable plants do not outcompete existing coal facilities until the very end of our outlook and only then in the case of solar. This means that the existing coal fleet remains a competitive source of bulk generation at around \$20/MWh (Figure 23).

**Figure 22: Tipping point 1: PV & wind LCOE versus coal and gas LCOE**



**Figure 23: Tipping point 2: PV & wind LCOE versus marginal cost of existing coal and gas**



Source: BloombergNEF. Note: LCOE are in financing years and use realized capacity factors; MC is marginal cost of generation.

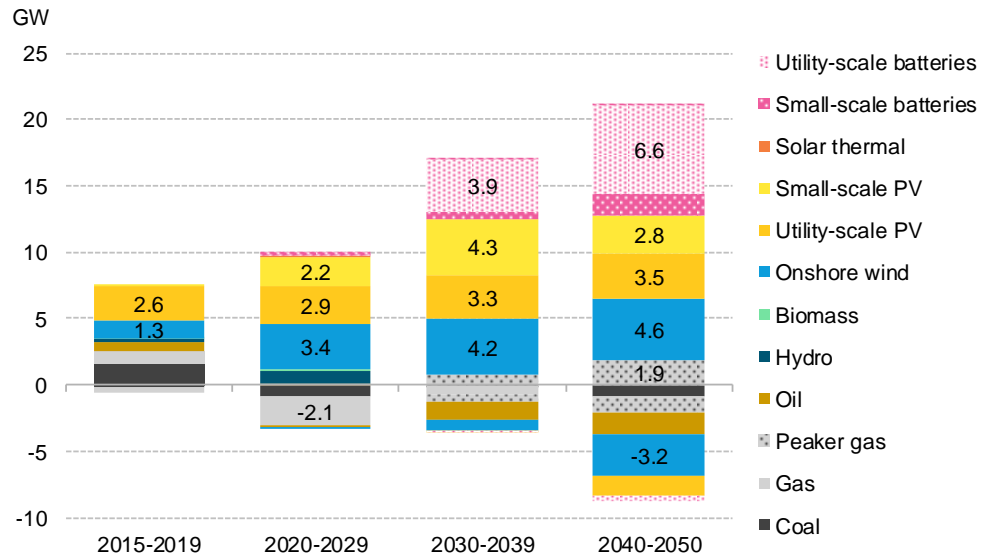
The evolution of Chile’s electricity system, viewed through the lenses of capacity additions and retirements goes through three distinct periods:

**Near to medium term (2020-2029):** Over the next decade, 1GW of coal and 2.1GW of gas capacity gets retired, replaced by 3.4GW of onshore wind and 5.1GW of PV, responding to steady electricity demand growth. This phase captures the currently planned project pipeline. As such, there are near-term additions of oil capacity, some growth of hydro, already under construction today, and coal retirements only occur according to Chile’s 2024 schedule.

**Medium to long term (2030-2039):** In the 2030s, some 2.6GW of thermal plants are expected to reach their end-of-life. Onshore wind, utility-scale and small-scale PV compensate for lost bulk electricity generation and sustained demand growth, adding nearly 12GW. Peaker gas, and in particular, batteries begin to kick in, providing the flexibility required by the increase in variable renewable energy. Beginning in the early 2030s, nearly 4GW of utility-scale battery capacity comes online, in addition to 700MW of peakers.

**Long term (2040-2050):** In the 2040s, variable renewable energy continues to grow, especially up to 2045. Nearly 11GW are added over the decade, backed by 8.3GW of utility-scale and small-scale batteries. From 2040, the amount of renewable capacity that reaches end-of-life is significant and requires new additions and associated investment. End-of-life wind retirements increase in particular, with more than 3GW retiring. At the same time, electricity demand growth slows, then fades out in the middle of the decade. After that, capacity build only emerges to make up for utility-scale PV and onshore wind retirements.

**Figure 24: Capacity additions and retirements**

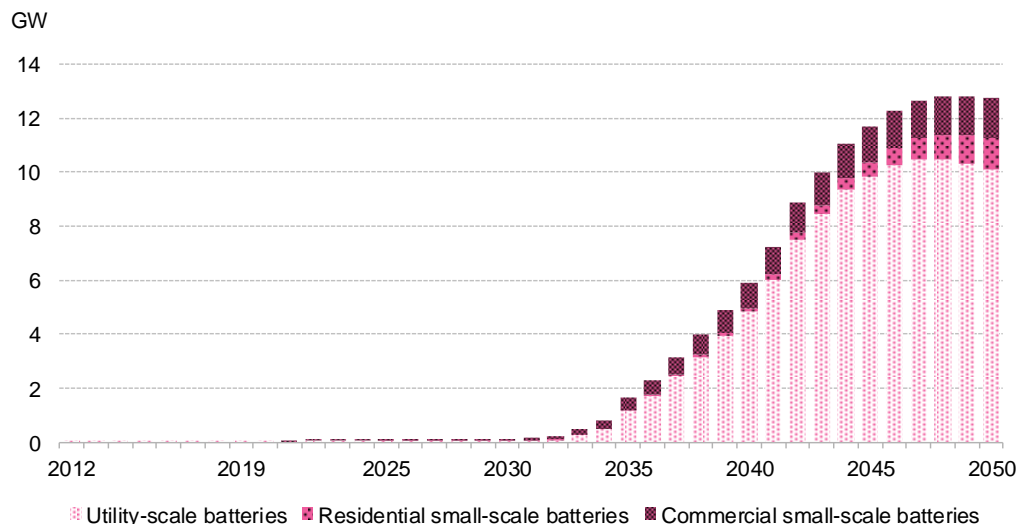


Source: BloombergNEF

## 2. Utility-scale batteries see a large uptake from the mid-2030s, providing critical flexibility to the system by shifting solar electricity towards the evening peak.

Large-scale batteries are the main driver of storage growth, complementing Chile’s solar buildout to shift electricity to evening hours and replacing back-up generation from oil-fired power. By 2050, some 13GW of battery storage are installed, more than the 10GW of fossil fuel generation retired over the same period. Of this, 10GW, or 80%, is utility-scale (Figure 25). Behind-the-meter, commercial small-scale deployment leads, as businesses enjoy favorable economics earlier due to scale and daytime demand profiles, creating shorter pay-back periods. Businesses can generate better returns from combined PV and battery systems, which generally results in earlier adoption. In total, storage presents an \$8 billion investment opportunity in Chile, nearly one quarter of the \$35 billion invested in new generation. Two-thirds of the investment in flexible capacity happen over 2036-45, when most of the battery build takes place.

**Figure 25: Cumulative installed capacity, battery storage**

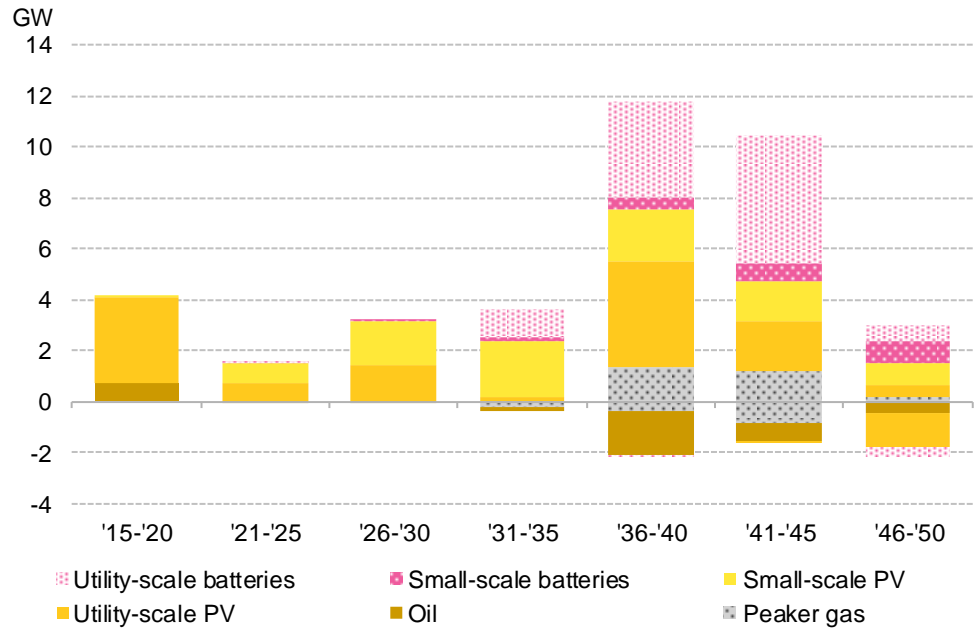


Source: BloombergNEF

As more renewables penetrate the Chilean power system and oil-fired power generation leaves the mix, flexible capacity is added. Batteries help renewables “go deeper” and make some of their generation dispatchable. Batteries complement PV and wind to allow them to shift electricity to valuable net peak hours, such as in the evening and morning. This allows variable renewables to achieve much higher penetration levels than without storage. The growth in solar, in particular, drives this uptake as utility-scale batteries shift electricity from daytime periods of oversupply and low value, to periods of high value when renewable output is at a minimum.

Falling battery costs are also key. Globally, the price of lithium-ion battery packs is already down 85% since 2010, and we expect them to fall another 65%, from \$176/kWh to \$62/kWh in 2030. From 2035 on, flexible capacity rapidly grows, from 6GW to just below 16GW by 2050 (Figure 26). Utility-scale batteries make up the largest share of this growth, but we see also an increase in peaker gas plant capacity, reflecting limitations in the amount of energy batteries can shift economically across the day. Batteries get more expensive the longer they need to discharge, so they are not good at helping to meet long-duration peaks or providing long-duration storage. Over longer periods, their economics are typically weaker than OCGT plants, which do not have run-time limitations.

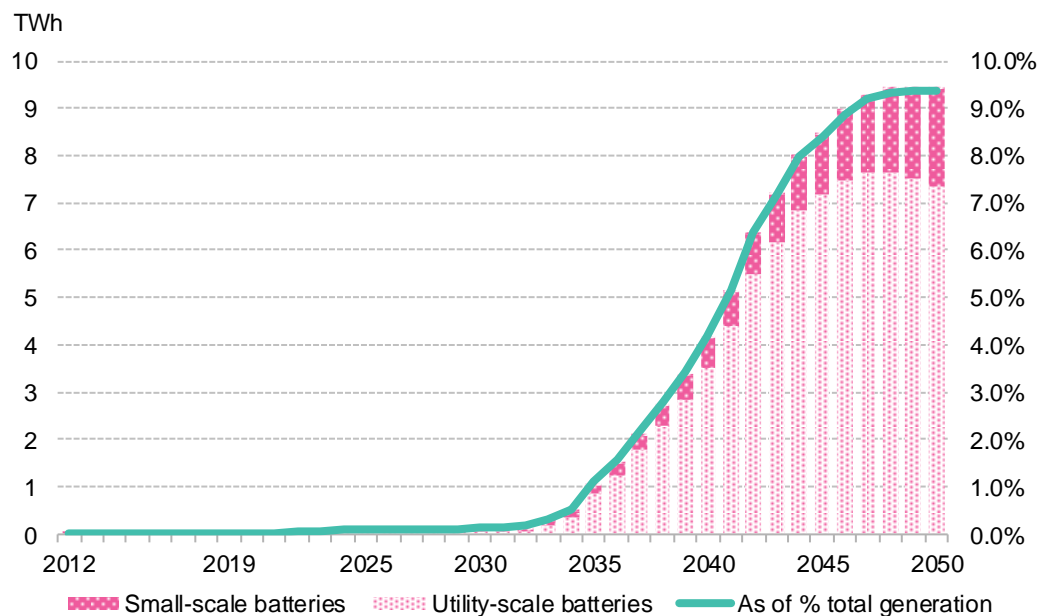
**Figure 26: Capacity additions and retirements: PV, thermal, flexible**



Source: BloombergNEF

The role of flexible capacity increases as more PV enters the system, with more than 9TWh being shifted by 2050. This is roughly 9% of electricity generation needs, and is well above the 7TWh generated by fossil fuels in that year. Utility-scale batteries provide around 70% of the shifted energy, followed by small-scale batteries, which provide 23% (Figure 27).

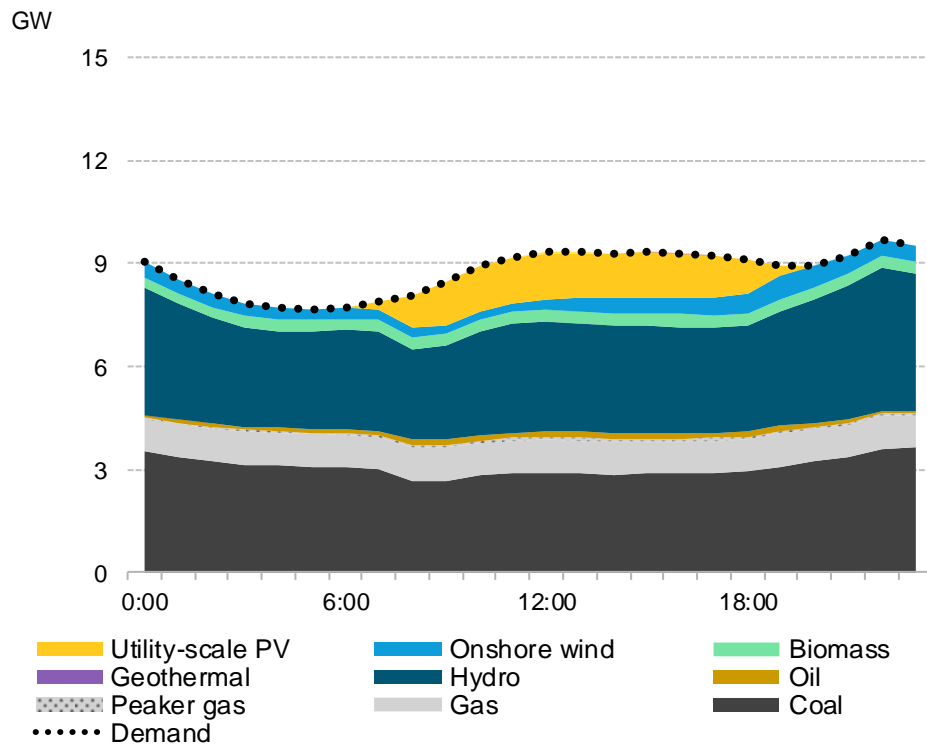
**Figure 27: Cumulative electricity shifted**



Source: BloombergNEF. Note: Small-scale batteries are assumed to shift 2.5h on a daily basis, utility-scale batteries 2h. Does not account for non-charging during periods of low renewables output.

The growth of wind and solar, and later flexible capacity, will have important implications for hourly generation profiles. Today, fossil fuels – mainly coal-fired power – make up more than half of the power generation mix, running at baseload, providing electricity to meet demand throughout the day. Generation from hydro is highest in the Chilean summer and is complementing generation from fossil fuels. Solar and wind only play a relatively small role on an average summer day today.

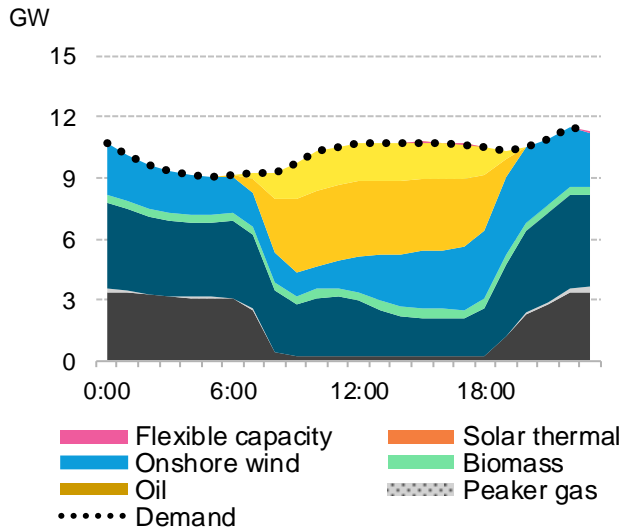
Figure 28: Typical hourly generation profile in 4Q, 2018



Source: BloombergNEF

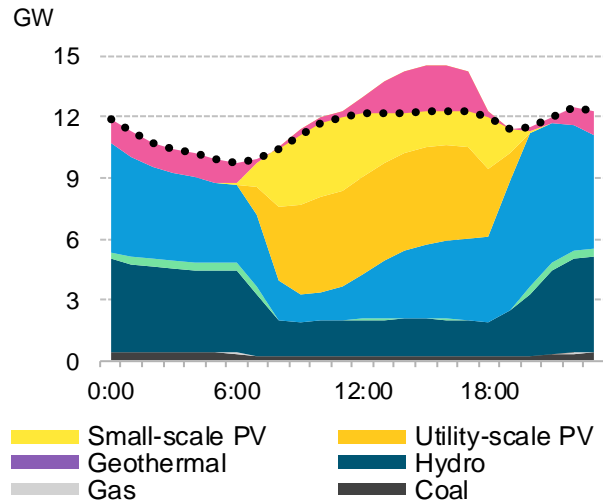
On hot days, air conditioning means that demand increases around midday, and peak electricity demand occurs towards the end of the evening, when we see coal-fired power generation and hydro plants ramping up to meet demand (Figure 28).

Figure 29: Typical hourly generation profile in 4Q, 2030



Source: BloombergNEF

Figure 30: Typical hourly generation profile in 4Q, 2050



Source: BloombergNEF

By 2030, gas almost completely disappears from the mix and variable renewables account for much of the generation needed during the day. The high penetration of variable renewables forces coal generators to operate much more flexibly in this environment, requiring them to either shut down or ramp down to minimum levels during daytime hours. In the evening, when solar generation drops, coal plants increase their output to meet the evening peak.<sup>1</sup>

Hydro is used flexibly to ramp up and down when the sun sets or the wind stops blowing. Gas-fired power is spinning at minimum load factors and gets only a fraction of the running hours. Whenever the sun is not shining and demand is relatively high, gas plants are chasing peak prices (Figure 29).

By 2050, battery storage capacity comes to play a significant role and charges during periods of high renewable output. It then discharges later in the day to meet some of the evening peak load after the sun sets, as well as overnight demand before the sun rises. Hydro is required to ramp up and down outside the hours of high solar output and complement batteries where necessary.

Whenever the sun is not shining and the wind is not blowing – and hydro and batteries can't provide enough flexibility, dispatchable coal generation is still necessary to meet demand – usually overnight. There will be weeks and months when renewables are producing more electricity than is needed and more than the battery fleet can store, leading to curtailment. However, as solar and wind get cheaper, they can be competitive despite not producing useable electricity for every hour of operation.

<sup>1</sup> Flexibly operating coal power plants will require changes to the operation practices and possibly investments in technical retrofits, particularly to older plants. The feasibility of optimizing coal-fired power plants for flexibility has been demonstrated in existing projects in the U.S., Germany, and other European countries. We consider flexibility from coal an integral part of minimizing system costs in future power systems marked by a high degree of variable renewables. We expect benefits from flexibility to outweigh investments in retrofits and costs from a reduction in generators' technical lifetime due to increased component wear and tear.

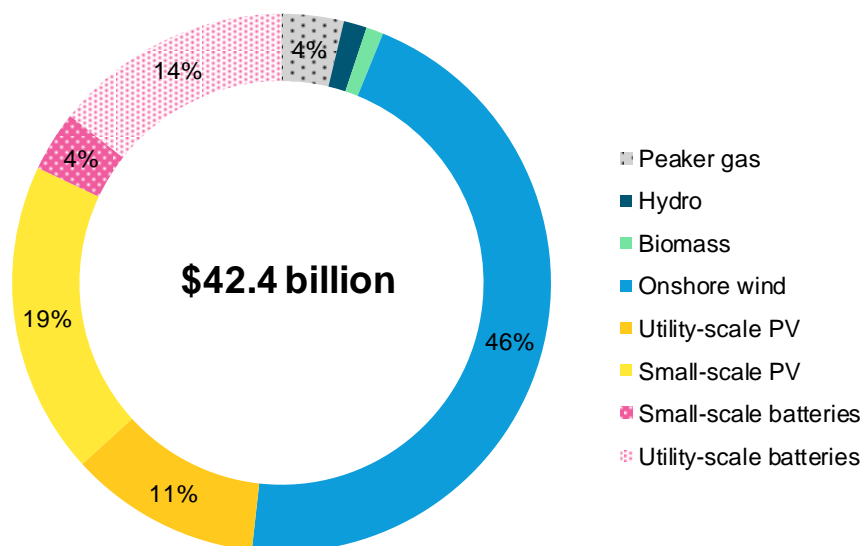


Additional flexibility will be required from all sides: demand flexibility (demand aggregation and large consumers), energy producers, transmission and distribution grids, but also from the regulator and the transmission system operator.

**3. New generating capacity will attract total investment of about \$35 billion, with 93% going to wind and solar, while storage presents an \$8 billion investment opportunity.**

A total of \$42.4 billion is invested in new power generating capacity and battery storage between 2019 and 2050, an average of \$1.4 billion per year. Power assets attract \$34.8 billion, of which 93% goes to wind and solar. Battery storage attracts another \$7.6 billion. Some 96%, or \$41 billion, goes to renewables and storage, with money committed to wind and solar dwarfing investment in thermal capacity (Figure 31).

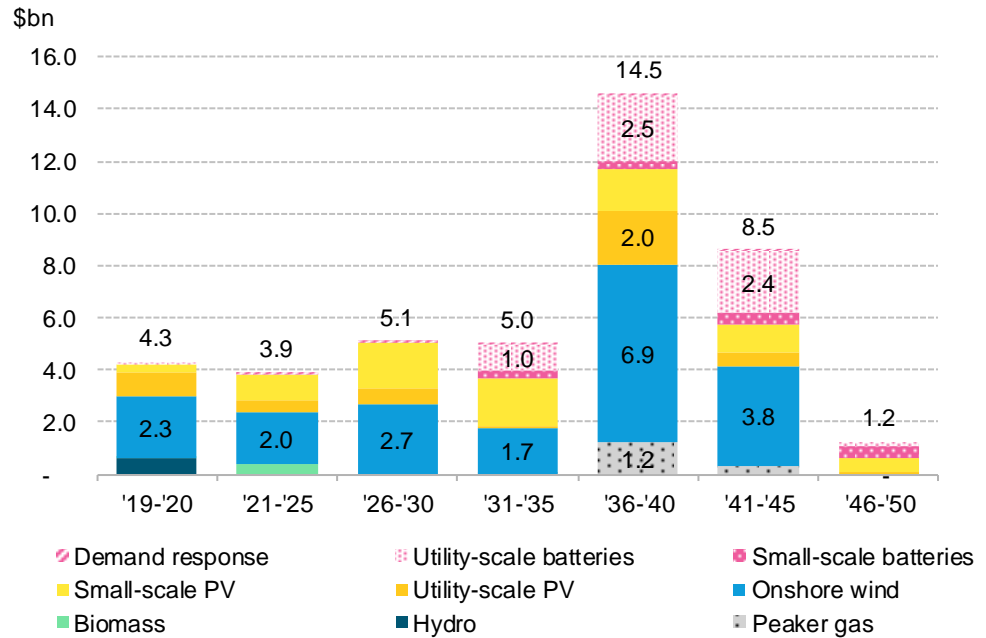
**Figure 31: Total investment (\$, real 2018), 2019-2050**



Source: BloombergNEF

A total of \$19 billion goes to wind and \$13 billion to solar (utility and small-scale), while fossil fuels attract just \$2 billion, destined for natural gas peaker plants. A wave of end-of-life retirements in the 2040s, including coal, gas and oil plants, drive investments in flexible capacity and renewables, but slowing demand growth means limited investment post-2045 (Figure 32).

Figure 32: Investments per technology, 2019-2050

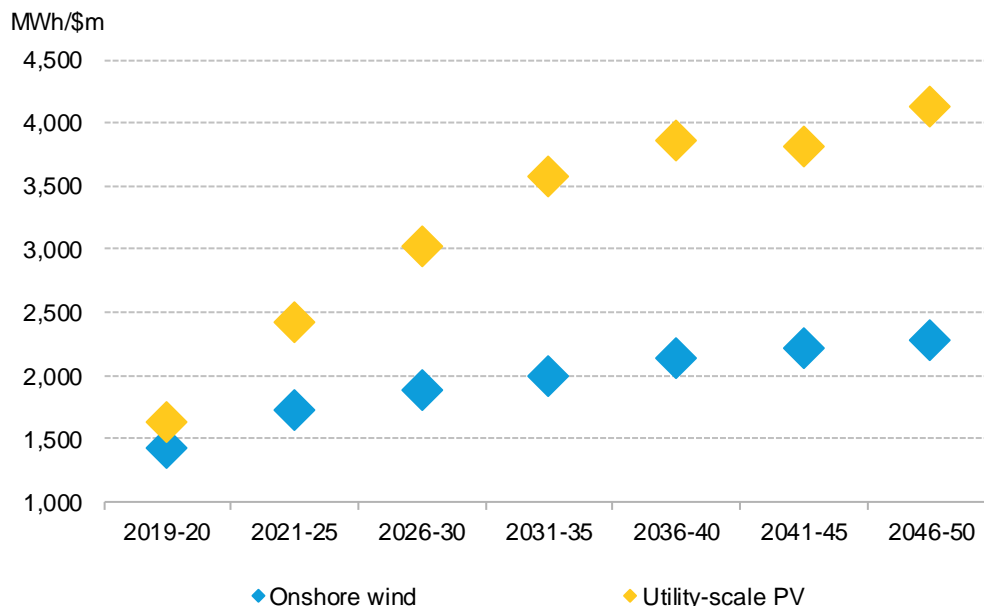


Source: BloombergNEF

Dramatic cost declines in solar technology have important implications for investment. Module costs are down 89% since 2010 and we expect another 34% decline from today to 2030 as manufacturers find further efficiencies throughout the production chain. Wind energy is getting cheaper too, though not quite as quickly: turbine costs are down 40% since 2010.

The most important advances in wind energy have been in turbine size and efficiency, not the unit price. Globally, capacity factors have risen from 21% in 2000 to 35% in 2019, thanks to better siting, newer turbine models with higher towers and improved operations and maintenance practices. Globally, we expect the cost of wind energy to drop another 36% by 2030, and 48% by 2050, to around \$30/MWh. However, normalized for investment dollars, the production of each technology begins to diverge sharply in later years, as cost declines on the solar side dramatically reduce its per unit cost (Figure 33).

**Figure 33: Energy generation per million dollar invested**



Source: BloombergNEF. Note: Assumes that the marginal electricity production of new onshore wind capacity is based on the same capacity factor as the entire fleet in the previous year. This leads to somewhat deflated estimates for the marginal electricity generation per investment dollar for onshore wind.

#### 4. Coal retains a long-term role in Chile’s system on an economic basis, unless there is robust policy intervention

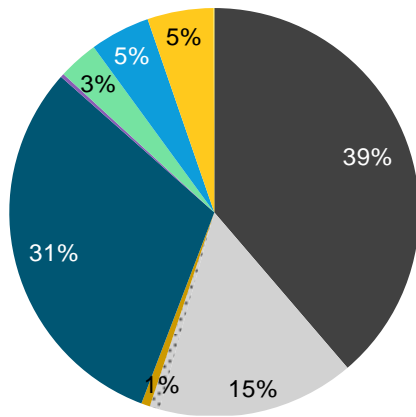
Excellent solar and wind resources in combination with cheap batteries, as well as stable generation from hydro slowly push fossil fuels from the mix. From a 13% share of generation today, wind and solar rise to produce two thirds of Chile’s electricity by 2050. Some 93% comes from zero-carbon sources. Coal drops from 39% to 6%. Onshore wind accounts for the majority in the short to medium term, and is providing 21% of total power generation in 2030. The contribution from solar grows from 5% today, to a share of more than 15% by 2040. It approaches 20% by the late 2040s.

Despite the fact that PV has almost twice the capacity of wind by 2050, the latter is set to produce roughly the same as solar, due to steady improvements in efficiency (Figure 34 and Figure 35). New turbine models are widening the range of locations at which wind can be developed economically, which means regions with relatively low wind speeds or with difficult site access are constantly being re-evaluated. Global capacity factors have doubled over the past 20 years and will continue to drive down the levelized cost of electricity from wind. We expect improvements in capacity factors to come from taller turbines that can access faster winds, and bigger swept-area-to-power-output ratios that increase the energy captured where the wind is less strong.

Coal experiences the largest decrease, tumbling from 39% of generation today to 6% by 2050. However, it remains important as the cheapest source of bulk generation to complement variable renewables. Without robust policy intervention, it retains a long-term role in Chile’s system on a purely economic basis. Back-up generation from retiring oil-fired power is replaced with flexible capacity – mainly batteries, but also peakers. Though operating at low capacity factors, peaker

gas plants nevertheless emerge as an important component of the future power system, helping to ramp-up quickly to provide security of supply in the renewables-heavy system.

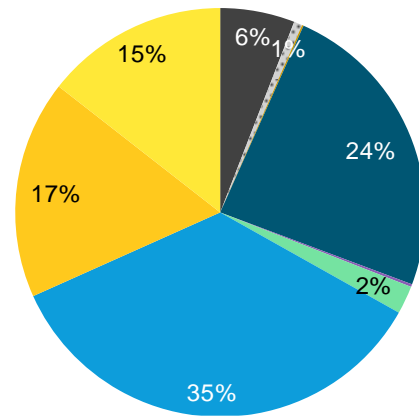
Figure 34: Chile generation mix, 2018



■ Small-scale PV  
■ Hydro

Source: BloombergNEF

Figure 35: Chile generation mix, 2050

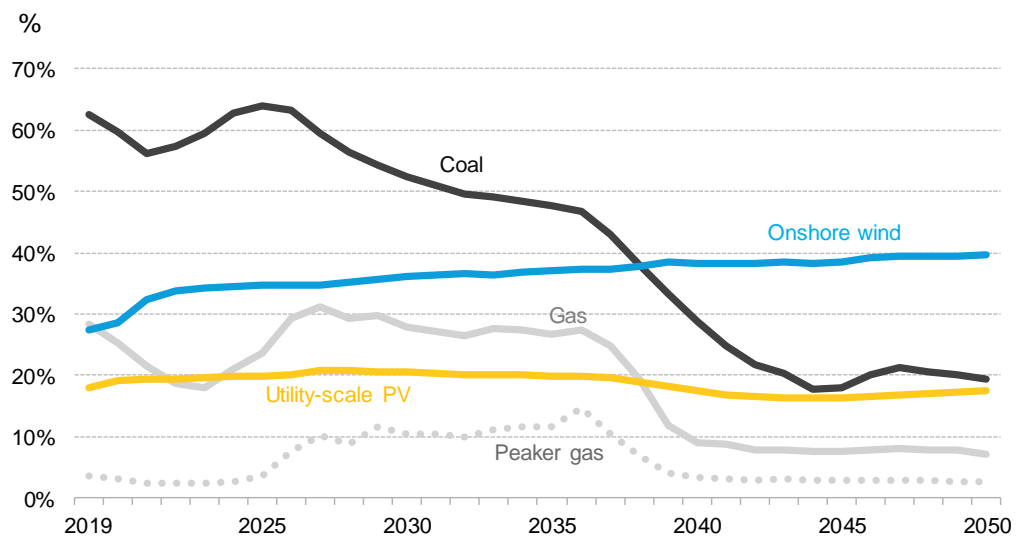


■ Utility-scale PV  
■ Onshore wind  
■ Biomass  
■ Geothermal  
■ Peaker gas  
■ Gas  
■ Coal

Source: BloombergNEF

Overcapacity, and the increased penetration from solar and wind mean that in the long run, fossil fuel sources are operated as backup technologies with low or very low capacity factors. While retirements lead to a boost in the medium term for the remaining coal and gas assets, capacity factors for coal and gas are set to decrease steadily. Prices for battery packs are gradually coming down, and so batteries are increasingly able to meet the need for flexibility after 2040. Excess generation from solar and wind is used to charge batteries, shifting energy to periods when the sun is not shining or the wind not blowing. We expect more efficient wind turbines and solar panels to capture more energy. Nevertheless, curtailment is expected to increase, affecting capacity factors beyond 2035, and hurting utility-scale PV the most (Figure 36).

Figure 36: Capacity factors



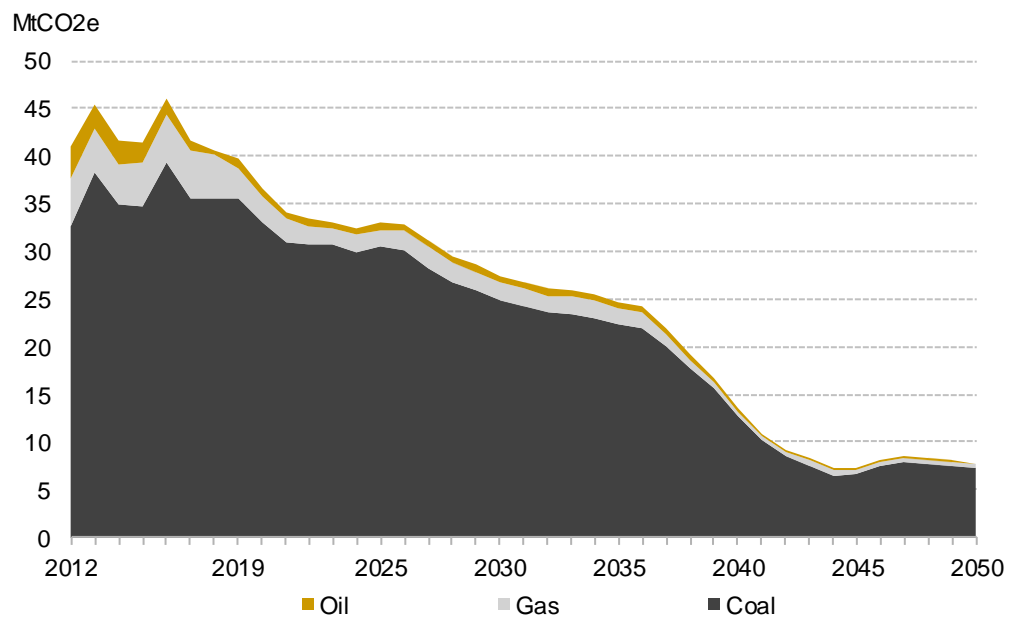
Source: BloombergNEF

**5. Chile's power sector emissions have already peaked in 2016; increased generation from solar and wind in combination with batteries steadily erode the need for bulk coal power.**

Chile's power sector emissions have already reached their peak – in 2016 at 46MtCO<sub>2</sub>e. Increased generation from solar and wind further erodes the need for bulk coal generation, steadily reducing emissions up to 2035, from 41MtCO<sub>2</sub> today, to just below 25MtCO<sub>2</sub>. Retiring oil-fired power capacity gets replaced by cheap batteries from 2035 on, speeding up the decline in emissions, which stabilize just below 10MtCO<sub>2</sub> by the early 2040s (Figure 37).

This represents a reduction of more than 80%, even as electricity demand rises by 33% over the same period. By 2050, Chile's power system has a carbon intensity of 77 gCO<sub>2</sub>/kWh, a 86% decrease compared to today's levels. A more aggressive coal phase-out would be needed for Chile to achieve a net-zero emissions scenario.

**Figure 37: Power sector CO<sub>2</sub> emissions**



Source: BloombergNEF

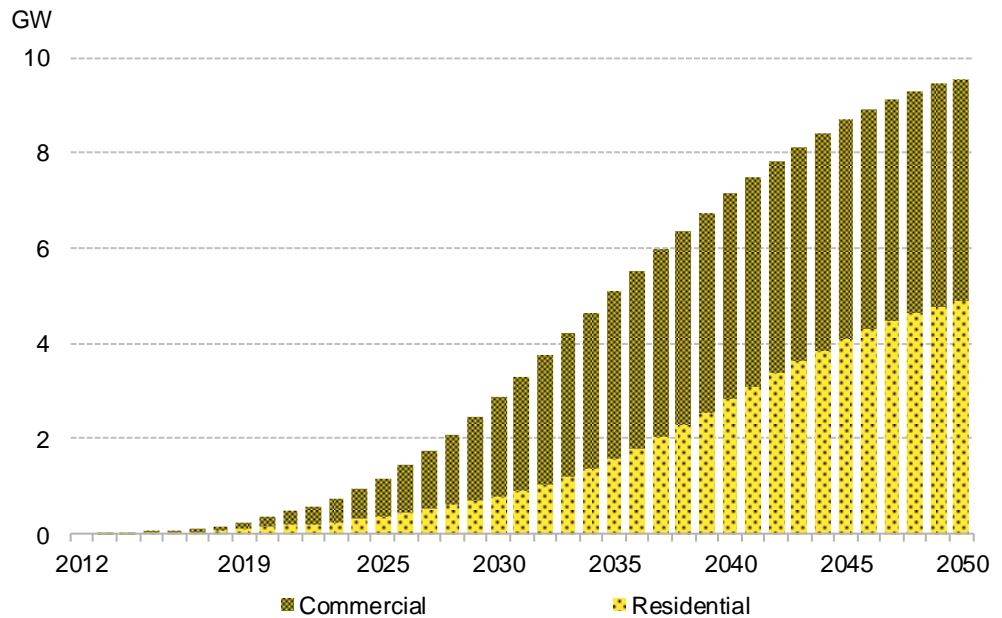
**6. Behind-the-meter generation is expected to see future growth driven by strong consumer uptake.**

Growth in behind-the-meter generation takes shape beginning in the 2030s, driven by strong consumer uptake. Consumer adoption dynamics, strong sun and economic incentives created by electricity retail tariffs combine to drive rooftop installation. Total installed capacity reaches 3GW in 2030, 7GW in 2040 and 9GW in 2050, from negligible levels today (Figure 38).

Though utility-scale PV may be more efficient from the perspective of total system costs and energy efficiency, small-scale PV is driven by very different dynamics. Its uptake reflects decisions taken by households and businesses looking to offset their electricity bills. Both

economics – in the form of payback periods or return on investment – and network effects support adoption.

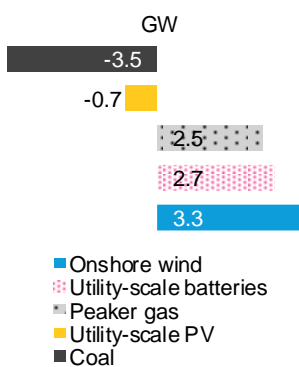
**Figure 38: Small-scale PV: cumulative installed capacity**



Source: BloombergNEF

Businesses use most energy during the day when they are open, and this fact makes possible much higher self-consumption. Large commercial facilities with ample roof space are particularly well-suited to adopt this cheap alternative to grid tariffs.

**Figure 39: Change in net capacity additions between base case and coal phase-out scenario, 2025-50**



Source: BloombergNEF

**7. If implemented, complete retirement of the coal fleet brings more wind and storage capacity online and earlier, reducing emissions but raising total investment needs.**

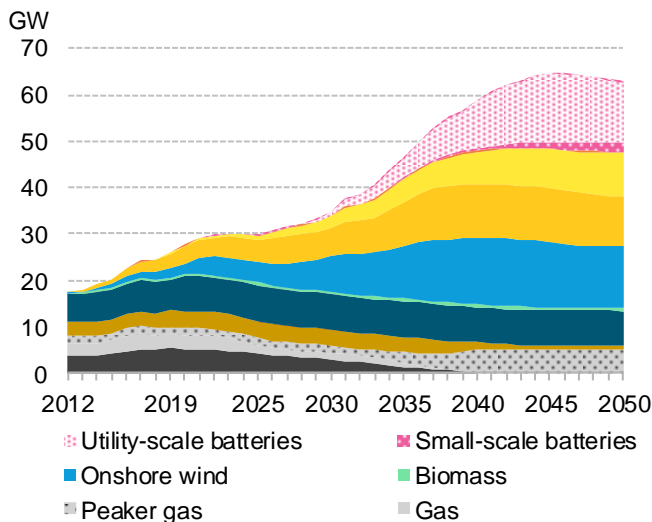
Chile has taken the first concrete steps to reduce coal in its generation mix. In June, it revealed the first phase of its coal retirement plan, in which Engie, Enel and AES committed to retire 1,043MW of coal assets by 2024. This is equivalent to 20% of Chile’s coal fleet. Engie followed up by decommissioning two plants with a combined capacity of 171MW.

Chile’s President Sebastian Piñera declared that it is the country’s goal to retire 100% of its coal fleet by 2040 but, so far, the government has only disclosed near-term steps. A total of 20 plants will remain operational after the first wave of retirements. The country aims to replace this fossil generation with clean energy. The government has now mapped out a clear plan for taking a fifth of its coal offline in five years. But significant questions remain about how the longer-run goal will be met.

In the event that Chile does implement a full retirement of its coal capacity by 2040, renewables – and especially wind and storage – stand to benefit significantly. Each of these sees faster growth than in our base case (Figure 39 and Figure 40). Under a coal phase-out scenario, wind and solar provide nearly three quarters of Chile’s power needs, or 73TWh, by 2050. Wind is by far the biggest winner (Figure 41). The technology replaces most of the retiring coal capacity, as it is able to provide power during the morning and evening hours when solar cannot and coal would

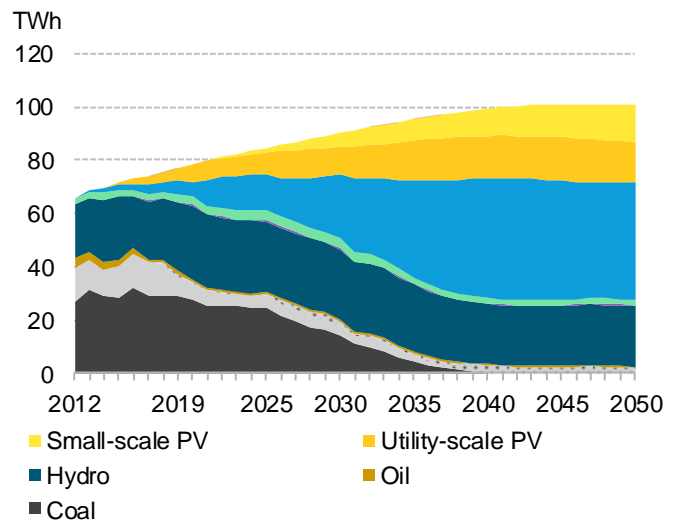
otherwise be producing. Wind also benefits from a favorable seasonal profile, generating electricity throughout the year including in winter months, when solar and hydro produce less electricity. Chile is expected to add 12GW of wind during 2019-50, which is 40% higher than in the base case. As coal declines through 2040, the contribution from wind accelerates, bringing more capacity online earlier. By 2050, wind meets around 44% of total demand, compared to 35% in the base case.

Figure 40: Cumulative installed capacity: coal phase-out



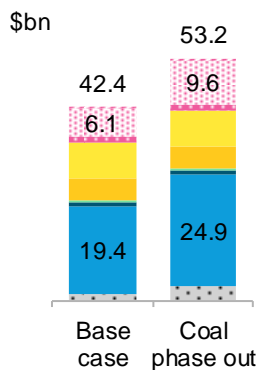
Source: BloombergNEF

Figure 41: Evolution of Chile generation mix: coal phase-out



Source: BloombergNEF

Figure 42: Change in investment between base case and coal phase-out scenario



Source: BloombergNEF

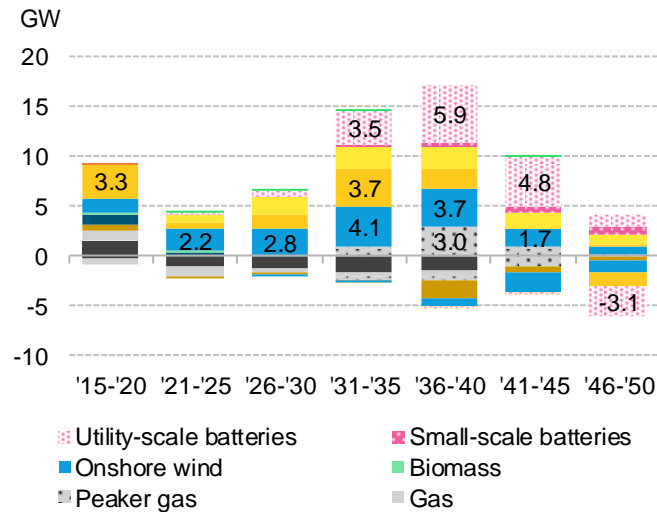
Fossil fuel generation makes up only 2% by 2050, compared to 7% in the base case. As coal leaves the mix, some of its back-up generation is replaced by peaker gas. By 2050, thermal capacity totals 6GW, some 90% of which is peaker gas. These thermal assets, together with batteries and hydro, help meet the flexibility needs of the system.

Full retirement of the coal fleet requires the country to add more renewable capacity than in our base case. Chile's power system increases to 63GW by 2050, which is 7% higher than we would expect without coal retirements. In addition to the growth in wind capacity, storage also expands as coal leaves the mix, peaking at 16GW in 2045. Battery capacity additions begin in earnest approximately five years earlier, starting in the early, as opposed to the mid 2030s.

A power system without coal will also require higher investment. Over 2019-50, Chile will need \$53.2 billion of investment in new generation and flexible capacity, \$10 billion more than in the base case (Figure 42). Total investment in generation swells by 21%, with wind investment reaching \$25 billion, nearly 50% of the total. Peaker gas is the only fossil fuel to attract investment, doubling compared to the base case, to \$3 billion. Investment in storage grows 46%. Batteries make up 24% of installed capacity by 2050.

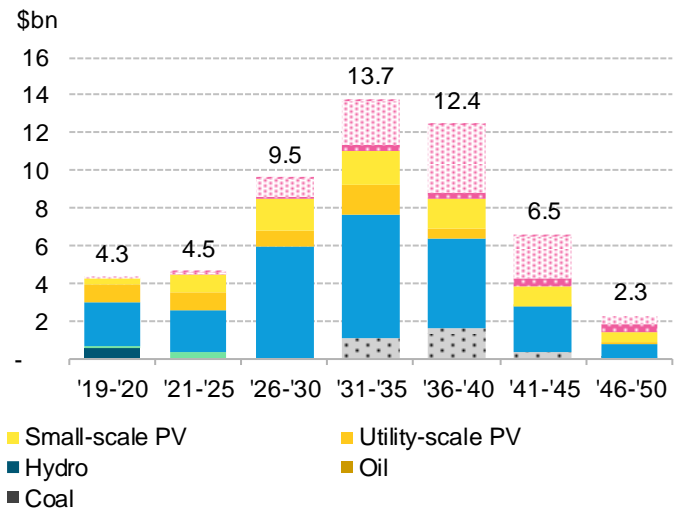


**Figure 43: Gross capacity additions & retirements: coal phase-out**



Source: BloombergNEF

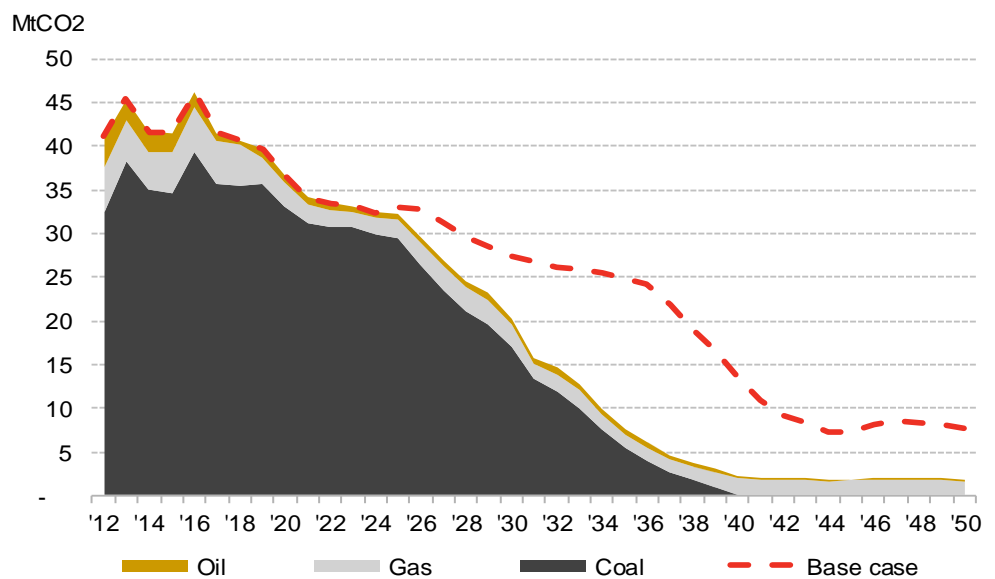
**Figure 44: Cumulative investments in new capacity (\$bn, real 2018): coal phase-out**



Source: BloombergNEF

Retiring coal has an important effect on emissions in Chile, both relative to current levels and to our base case. Such a policy would reduce emissions by 44% by 2030 and 95% by 2050 compared to today's levels. Under this scenario, emissions plunge below 2MtCO<sub>2</sub> by 2050, compared to 8MtCO<sub>2</sub> in our base case and cumulative emissions through 2050 are 23% lower (Figure 45). Overall, the carbon intensity of the power system falls from 564gCO<sub>2</sub>/kWh today to 19gCO<sub>2</sub>/kWh by 2050, a 97% cut. This would make Chile one of the most decarbonized power systems in the world.

**Figure 45: Power sector CO<sub>2</sub> emissions, coal phase-out versus base case**



Source: BloombergNEF

## Section 4. Policy options

Chile is rapidly progressing towards an energy system built around renewable energy. As our modelling illustrates, economics alone can drive this transition, though Chile's proactive de-carbonization policy framework may hasten it. However, the rise of variable sources creates new challenges, costs and requirements. Supportive policy, infrastructure and technology will be required to meet the reliability and flexibility demands of the clean, low-cost system of the future. We highlight potential policy options to support the trajectory of Chile's energy system.

In 2016, the Chilean government released the Energy 2050 Roadmap, which lays out the long-term plans for the power sector. Key goals for 2050 include: at least 70% of the electricity generated in the country to come from renewable energy sources (including large hydro), power outages not to exceed one hour per year in Chilean territory, and Chile to be among the three lowest OECD countries in terms of average industrial and residential electricity prices. Achieving these goals will require market design decisions as well as introduction of new policies, while deployment of new technology and infrastructure must be aligned with the system's changing needs.

### Continue active infrastructure planning and deployment.

With increasing volumes of solar and wind, transmission issues can be extremely significant, making it critical that the right measures are implemented to ensure that necessary investments in the transport system take place. In addition, flexibility mechanisms must be designed and put in place. Chile has taken encouraging steps towards addressing mismatched capacity and transmission, but there remains a clear risk that the volume of new renewable capacity will far exceed even the expanded transmission capacity.

Batteries associated with renewable assets can also help to manage the load factor of power lines. Additionally, new transfer control system can help to optimize the use of the grid infrastructure. Chile currently does not have high-voltage, direct current (HVDC) lines, which could be valuable to connect remote renewable assets to the grid, as the technology offers much lower losses than AC lines. Recently commissioned transmission lines are already mitigating price volatility and curtailment to an extent. But other factors could complicate the situation, namely weaker-than-expected demand growth and a massive 18GW of permitted renewable power projects and 2.9GW of potential capacity seeking environmental permits.

### Consider a robust carbon price.

Existing coal plants are currently the cheapest form of bulk generation in light of Chile's limited carbon price. But coal-fired power is ill-suited for ramping up and down quickly. Gas, and especially peaker plants, are better placed to fill this role. Chile has already implemented a carbon tax to make fossil generation less competitive, requiring power plants 50MW or larger to pay \$5 per metric ton of CO<sub>2</sub> emissions as of 2017. However, the effectiveness of the carbon tax is limited, as it is not taken into account in determining dispatch, preserving the position of coal generators in the merit order.

A higher carbon price could allow gas plants to play the role they should in the merit order, improving overall system efficiency and complementing steps the country is taking to take its coal offline. Under current market conditions, the 2040 retirement schedule will ultimately be required to bring coal generation to zero, as just 2GW of coal plants are retired by 2050 on an economic basis, leaving 3GW online.

### Incentivize technology aimed at increasing flexibility.

The development of flexible capacity in Chile is still at an early stage. But without new forms of flexibility, a renewables-led power system will develop inefficiently, over-reliant on backup from fossil fuels and with renewables capacity that is oversized. Efficiently integrating large volumes of clean generation will require either storing excess renewable electricity for periods of high demand – or shifting excess demand to periods of high green power production, or most likely, both.

Deployment of storage in Chile to date has lacked incentives. A comprehensive regulatory framework for storage is needed. In the wholesale power market, this requires thoroughly reviewing the current market rules, clearly establishing energy storage as a standalone technology in market operational manuals, considering the operational and physical characteristics of storage in how it operates, and reviewing how and if valuing the characteristics of storage relative to other technologies makes sense.<sup>2</sup> Additionally, storage capacity could be included in power auctions or transmission tenders.

Some support for peaker plants may also prove important. Many will not be running often so ensuring some capacity is sufficiently remunerated will ensure these remain in the system. A lack of run-hours could force them to retire unless alternative revenue streams are available to cover their fixed operating costs. The minimum capacity factor for such plants will vary between markets.

Finally, unlocking demand-side flexibility can reduce load during periods of high electricity demand, helping to limit the need for high-cost peaking plants, to defer capacity upgrades, and to prevent potential supply-demand imbalances. Demand-side flexibility includes dispatchable demand response, in which customers, mostly large commercial and industrial, reduce consumption during peak incidents; as well as time-of-use load shifting, where customers shift load to low-demand hours on a daily basis, encouraged by time-varying pricing schemes. Dynamic pricing and aggregation mechanisms can encourage residential and business customers to invest in technologies such as small-scale storage.

### Integrate and incentivize distributed resources rationally.

Exceptionally strong sun, along with the economic incentive posed by residential power prices and consumer uptake dynamics, will make small-scale PV appealing to many consumers – provided they have the financial resources to install such systems. Lack of financing remains a key barrier in the way of a take-off in small-scale PV in the country. Providing special credit lines could help.

A more decentralized power system is also a more complex power system. Utilities will require sophisticated software to manage variability of supply. The need is greatest at the distribution-

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<sup>2</sup> One example is that Chile currently does not operate an ancillary services market, hence the fast-responsiveness of batteries, which may be beneficial to the Chilean system, is not compensated as such services are currently operated in Chile. A policy is planned to enter into force in 2020.

level, which will have to accommodate dynamic two-way power flows. Software and control systems, designed to monitor and dispatch energy resources, will be a must. But control systems require detailed data about the real-time operating state of the grid. That implies more deployment of network sensors and integration of other data sources such as smart meters.

Much of the policy support for small-scale PV and storage will also comprise market enablement. Barriers to deployment typically relate to permitting procedures, technical standards, grid-connection rules and procedures, and grid-capacity issues. Chile's government has set a broad goal for the expansion of distributed generation, including quadrupling current capacity of renewable small-scale systems (under 300 kW) by 2022. As the role of distributed energy increases in the following decades, improving transparency, reducing unnecessary bureaucracy and ensuring the rules for small-scale generation are clear will be critical.

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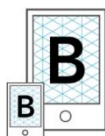
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