



Challenges faced by markets with rapid decarbonization and high dependence on solar generation: California and Chile Case Studies

June 2024

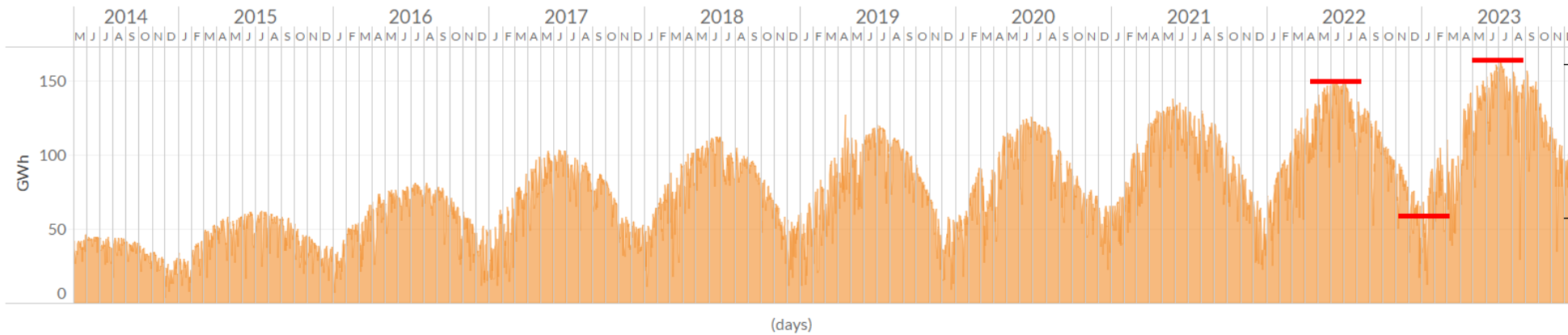
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- 1) Comparison Chile and California power system structure
- 2) Adequacy and reliability challenges
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California has rapidly integrated solar, availability of solar and wind are significantly higher in the spring and summer

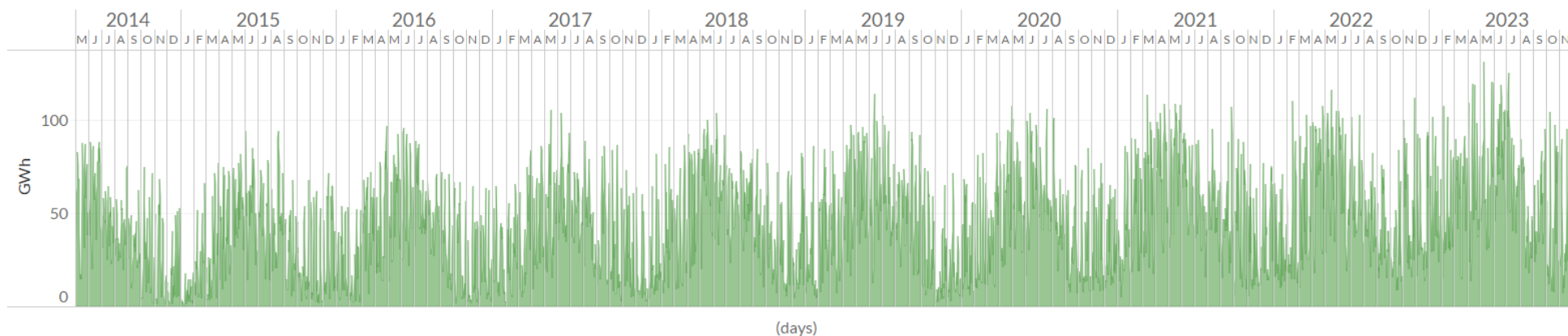
Daily historical solar dispatch in CAISO



Solar generation has been steadily increasing over time exceeding 150 GWh per day in 2023.

However, the solar generation was 60% lower in the winter than in the summer. The difference observed in solar production between the summer and winter has been consistent over time.

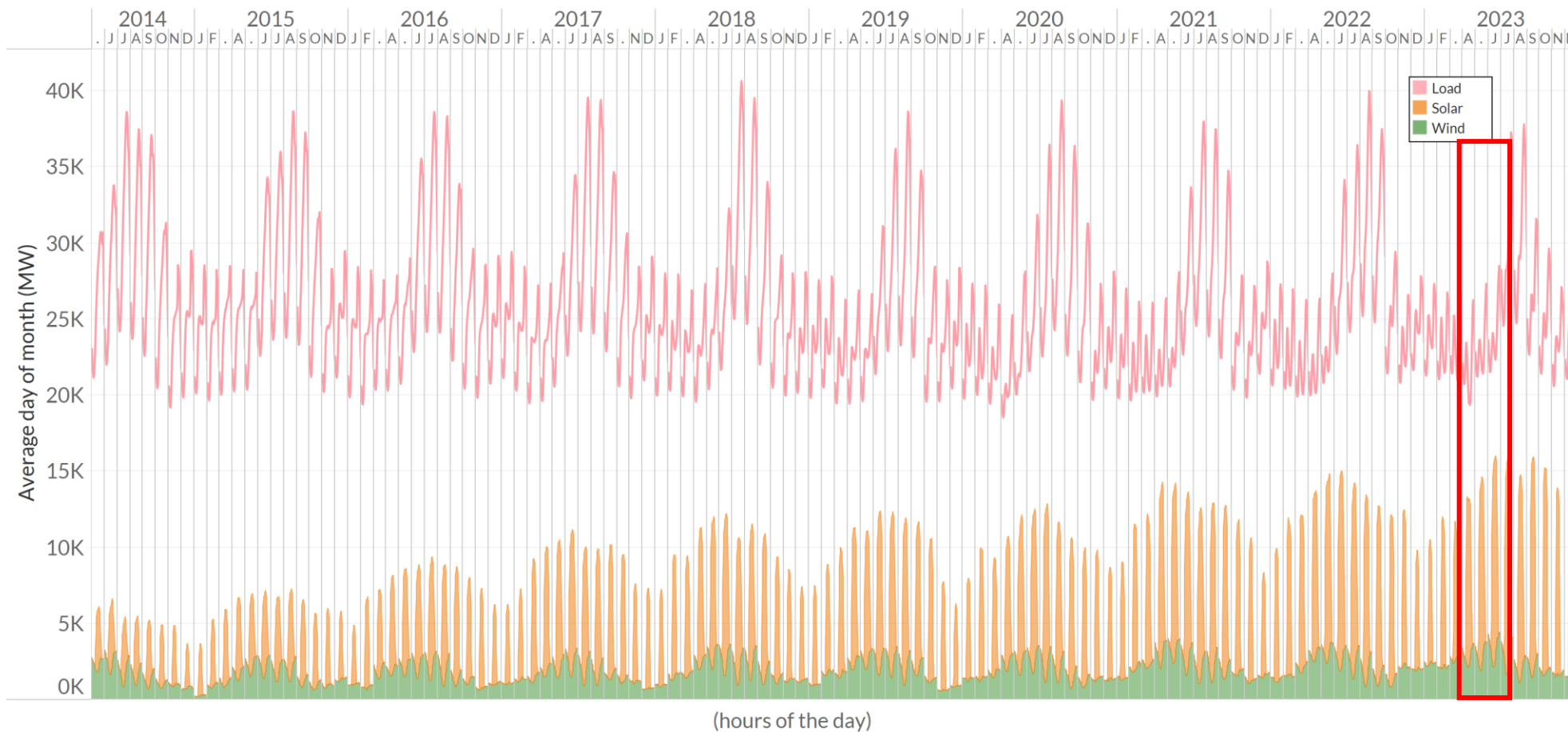
Daily historical wind dispatch in CAISO



Wind generation is seasonal and peaks in the spring & summer.

In the spring in CAISO wind and solar generation reach its maximum, **inodú** however the load remains low and increases in the summer

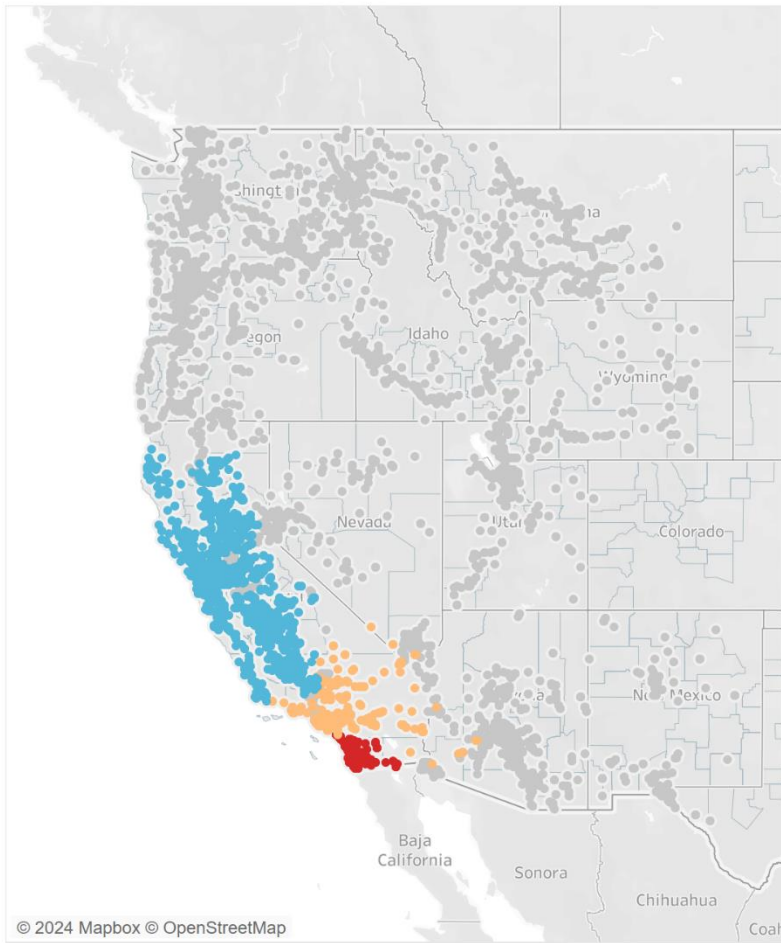
Renewable dispatch compared to system load in CAISO



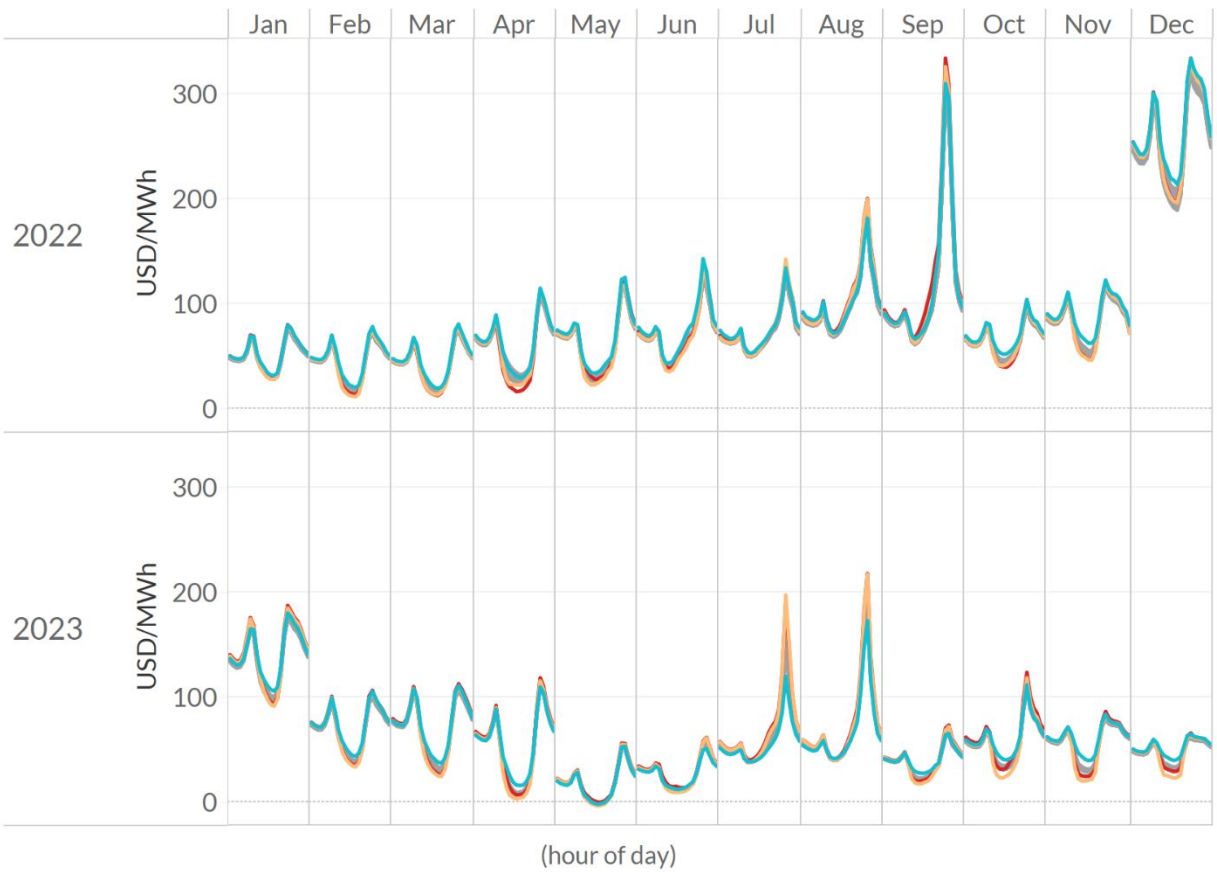
In CAISO, demand is at its lowest during the spring March through May this coincides with the period with highest levels of wind and solar generation, the renewable supply on average is highest during the day.

Peak demand in the spring occurs around 8pm and load on average is lower, when the renewable generation is at its highest.

The lowest spot prices are observed during the day in the spring when the supply of renewables is high and the load is low



Average historical spot prices for WECC's region



Spot prices outside of CAISO are coupled to CAISO prices.

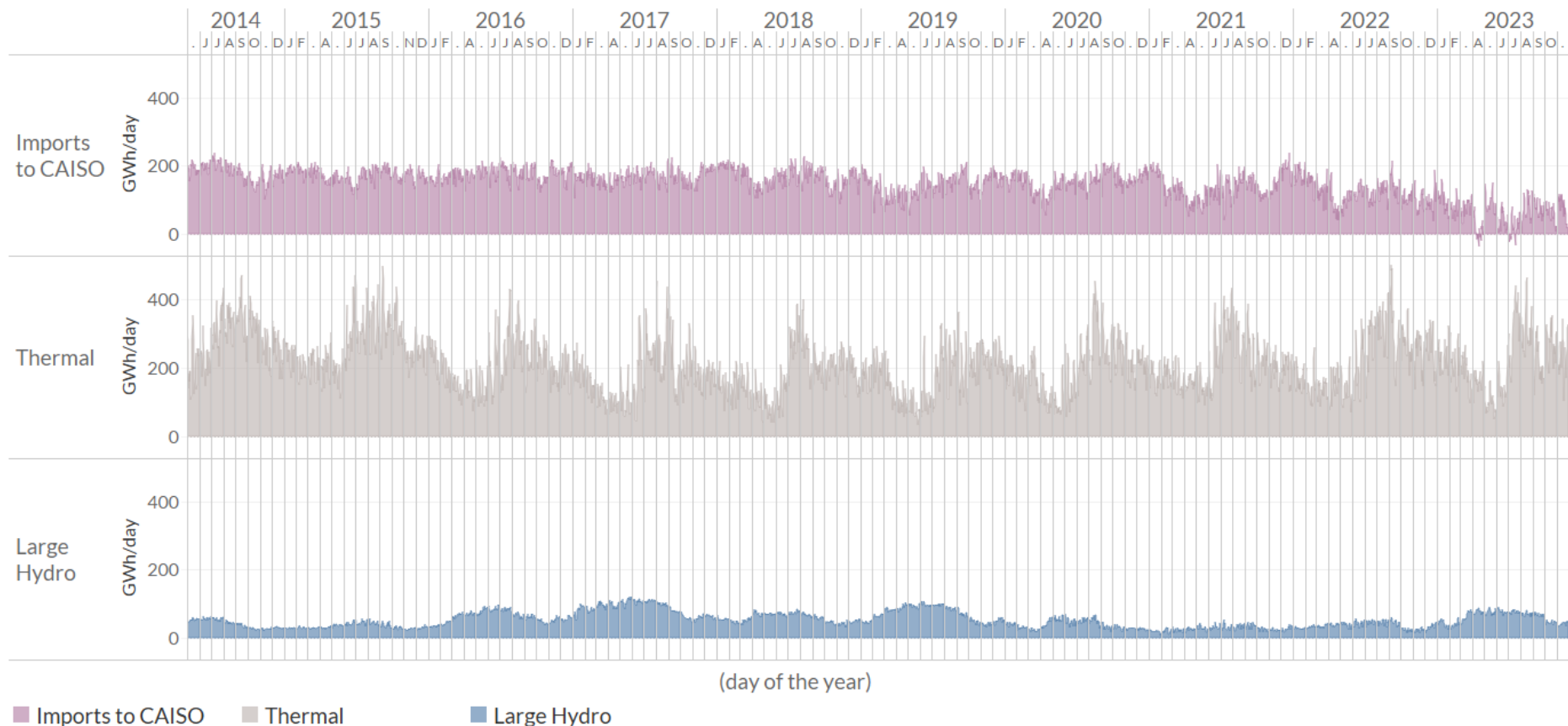
In 2023, the lowest day ahead spot prices during the day were observed in March-June. In 2023, April was one of the most attractive months in terms of day ahead spot price differentials.

In the summer, day ahead spot prices peak as the demand goes up significantly in CAISO.

*Day ahead spot prices

Dynamics of gas generation, hydro generation & imports becoming very important to balance the system in CAISO

Daily generation and imports in CAISO



CAISO exported energy during the day in 2023, which is a significant break from historical trends.

Hydro energy availability from NW and WECC was at its lowest levels in 22 years, reducing the amount of energy available to import to CAISO.

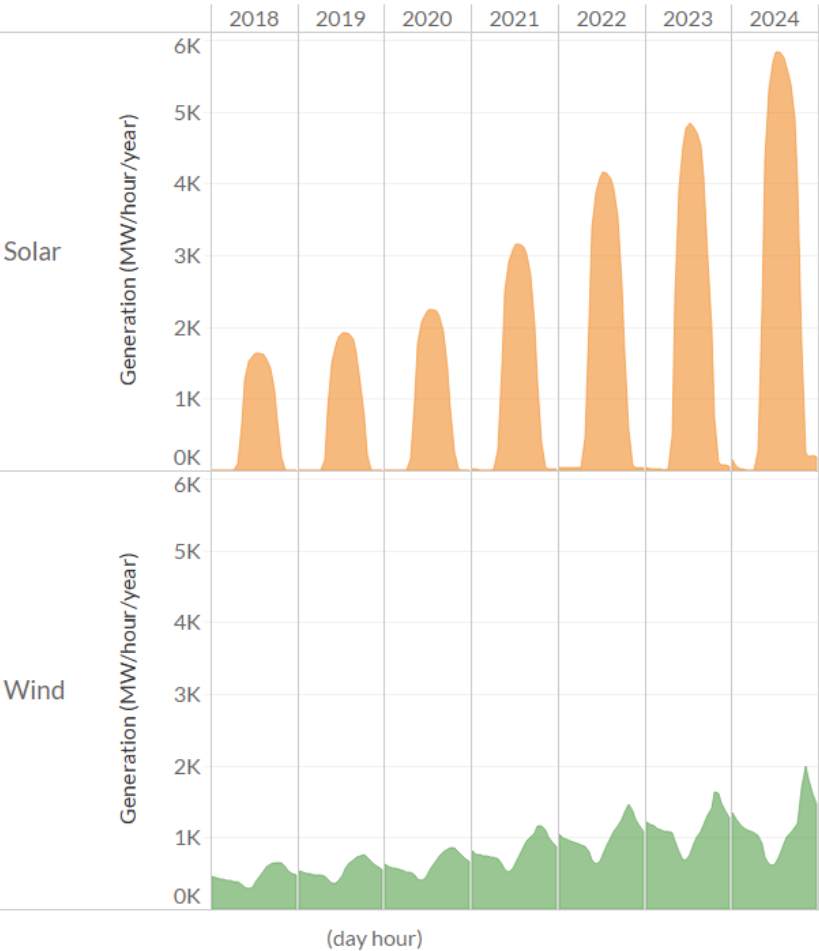
Hydro generation has varied significantly over the past couple of years which impacts needs for imports and gas generation.

Thermal generation in CAISO has been increasing since 2018, showing the challenges with the decarbonization of the electricity system

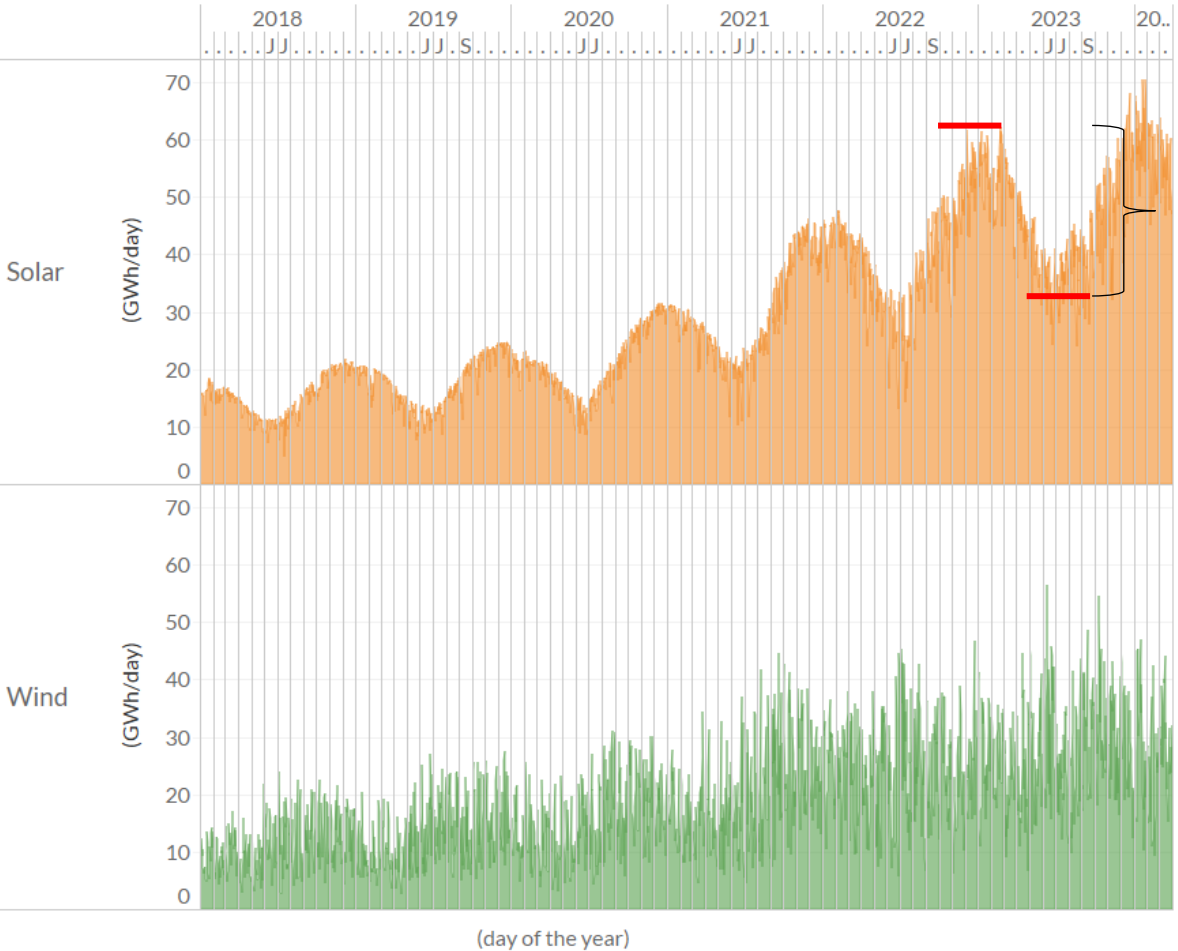
Like California, Chile, has rapidly integrated solar, the availability of solar is significantly higher in the spring and summer



Average Renewable generation in Chile



Daily Renewable generation in Chile



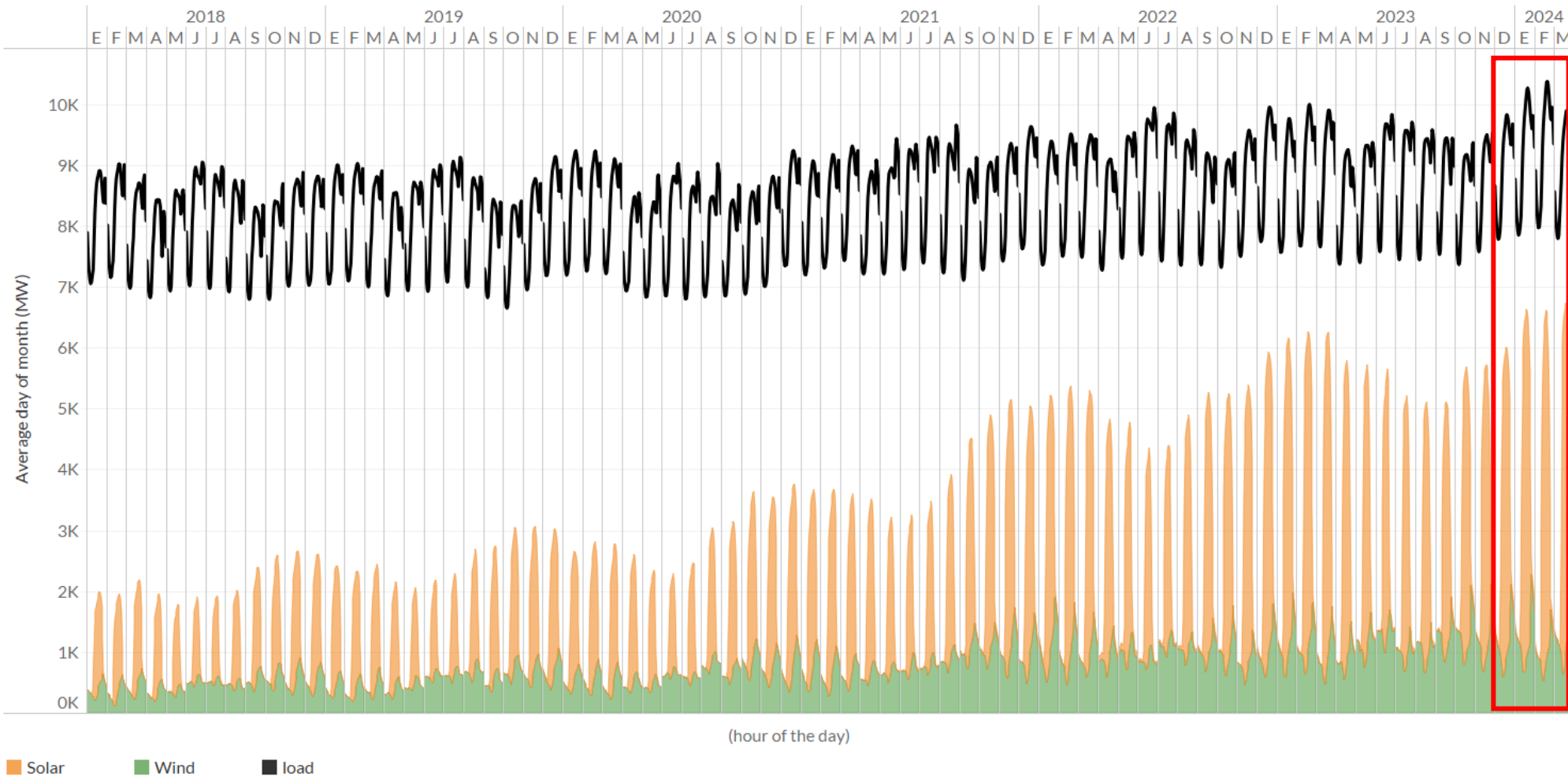
Solar generation has been steadily increasing over time exceeding 65 GWh per day in 2024.

However, solar generation was 50% lower in the winter than in the summer. The difference observed in solar production between the summer and winter has been consistent over time.

Wind generation in Chile is less seasonal than in CAISO.

In the summer and spring solar generation reaches its maximum in **inodú** Chile, the load does not vary as much as in CAISO over the summer

Renewable dispatch compared to system load in Chile



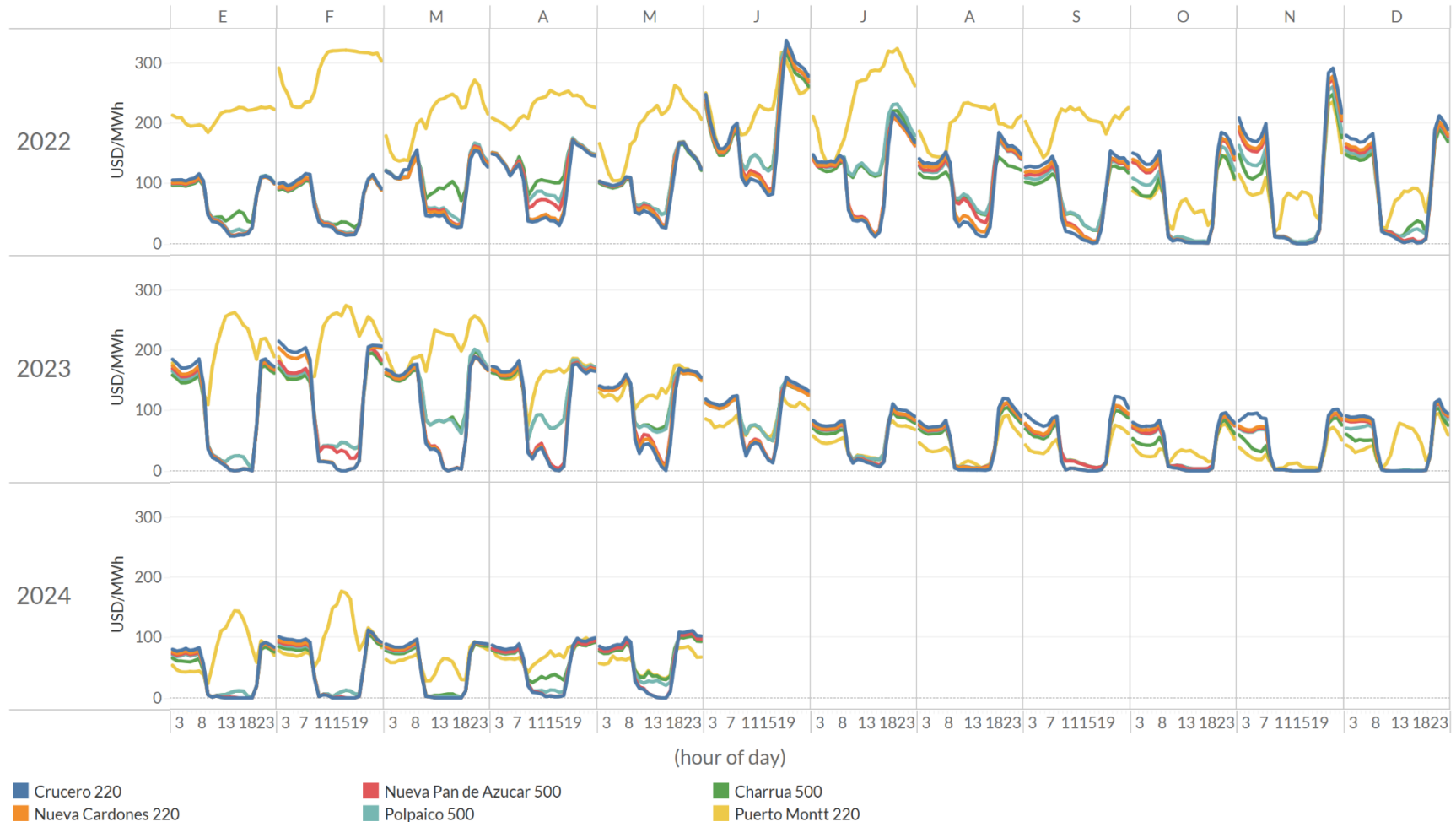
In Chile, from December through March solar generation reaches its maximum. The load does not increase as significantly over the summer, however the load increase this summer (2024) was more significant than for previous summers.

Peak demand occurred between 2-4pm during the summer in 2024, which coincides with the solar peak.

The oversupply of solar generation during spring and summer has led **inodú** to persistent zero spot prices across the system



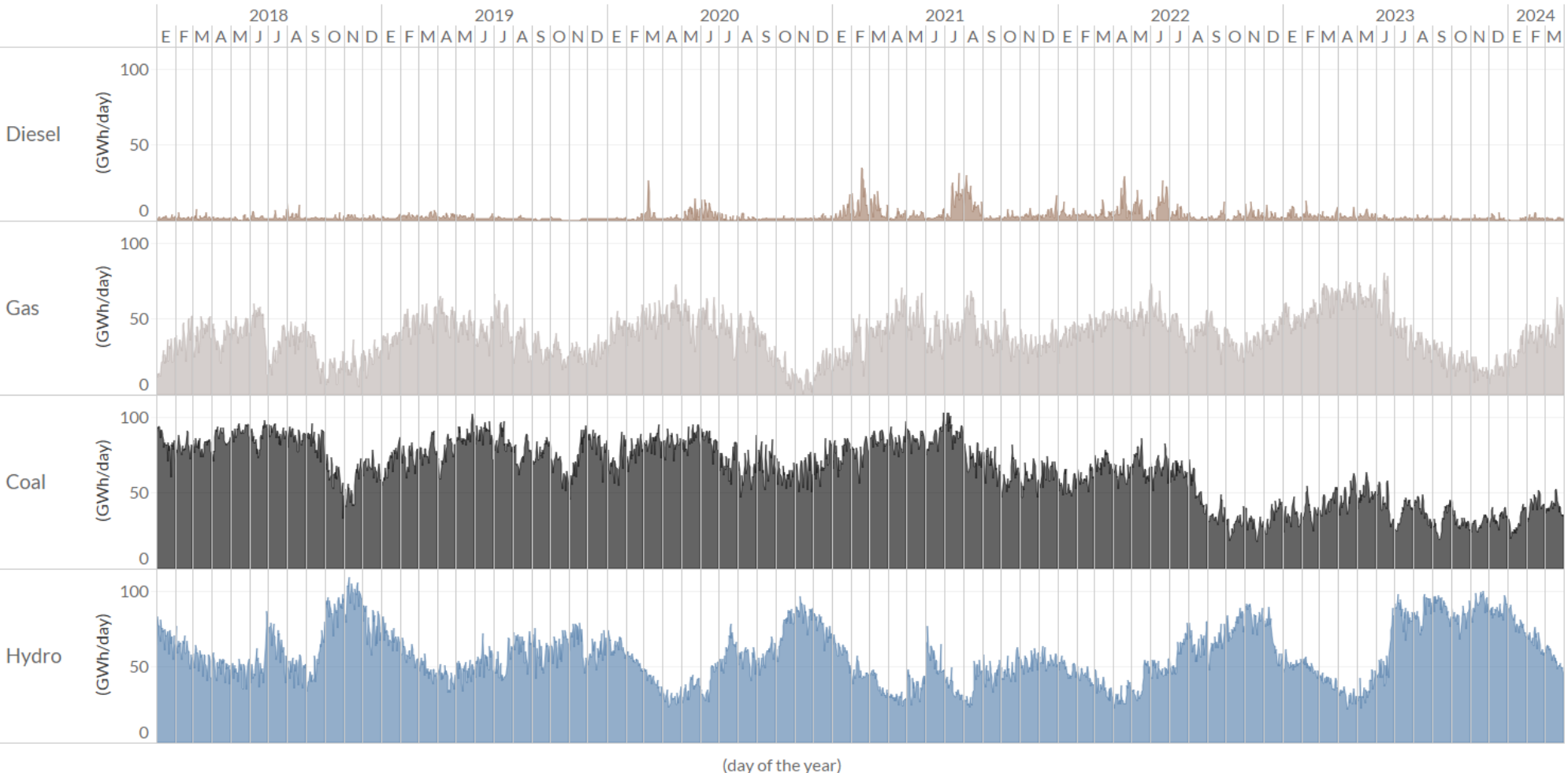
Average hourly spot prices for representatives nodes in Chile



In Chile, coal facilities have been retired and their availability has decreased, increasing the reliance on gas & hydro to balance the system



Daily generation by technology in Chile



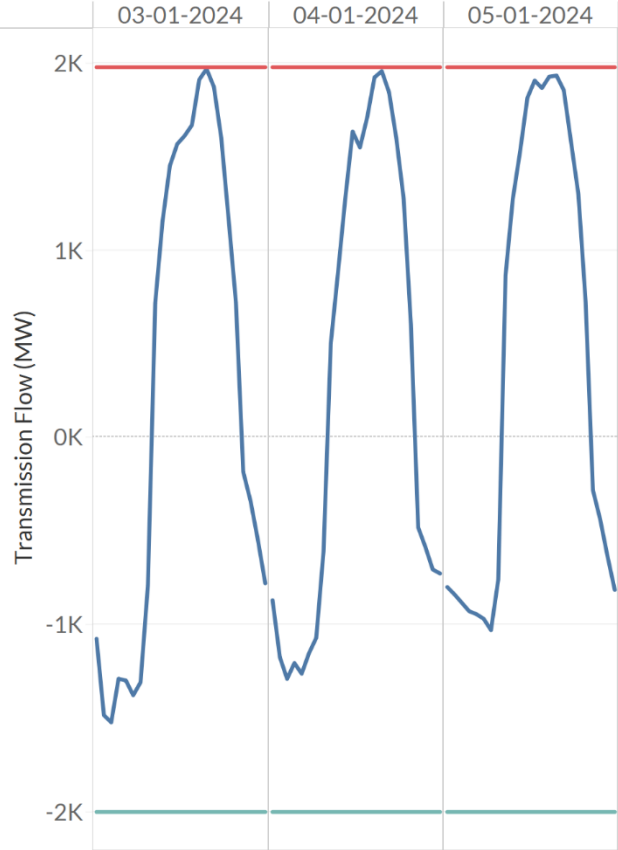
In Chile, gas generation has taken a more active role in complementing hydro generation to balance the system specially during periods where wind and solar supply are limited.

Gas generation is used to address the seasonality of hydro, wind and solar. Additionally, gas generation plays an important role supplying energy during the night.

The low cost and abundance of solar resource in the north has led to significant development and transmission congestion from the North to Central Region

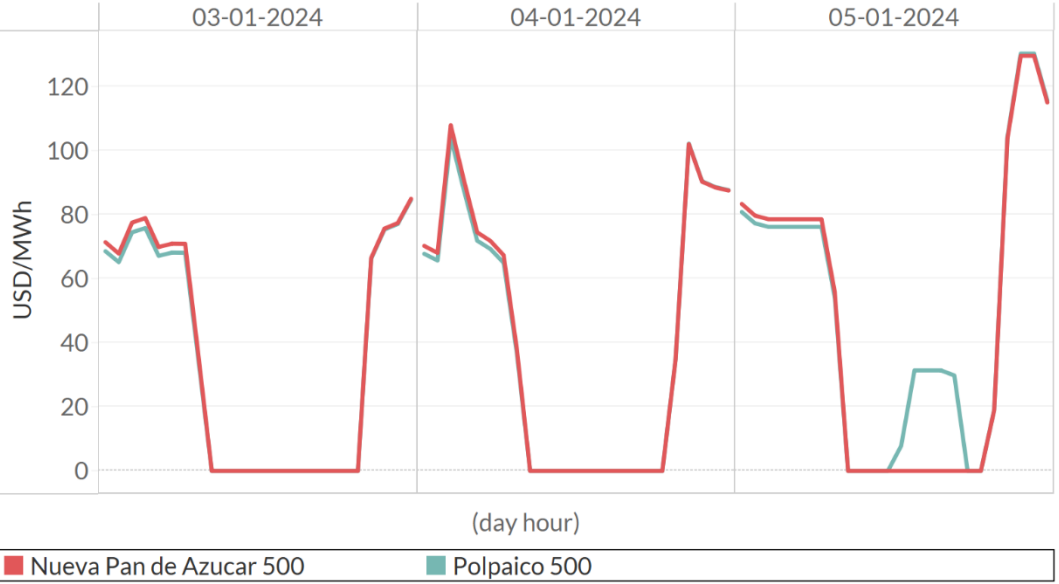


Historical Transmission flow in Nueva Pan de Azúcar – Polpaico 500 kV Line



■ Max Line Flow
■ Min Line Flow
■ Historical Transmission Flow

Spot prices decoupling in north – center nodes by transmission constraints



Oversupply of renewables combined with limited flexibility of thermal/hydro generation has been the primary cause of zero spot prices and curtailment during the day.

However, there are periods where congestion emerges between the north and central region.

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- 3) Adequacy remuneration challenges



Transitioning electricity systems creates a challenge to gracefully manage the balance of decarbonization efforts & reliability

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Chile & California both have decarbonization pressure

In both places full decarbonization of the electricity generation sector must be reached by 2050.

Chile significant pressure to decarbonize the electricity sector

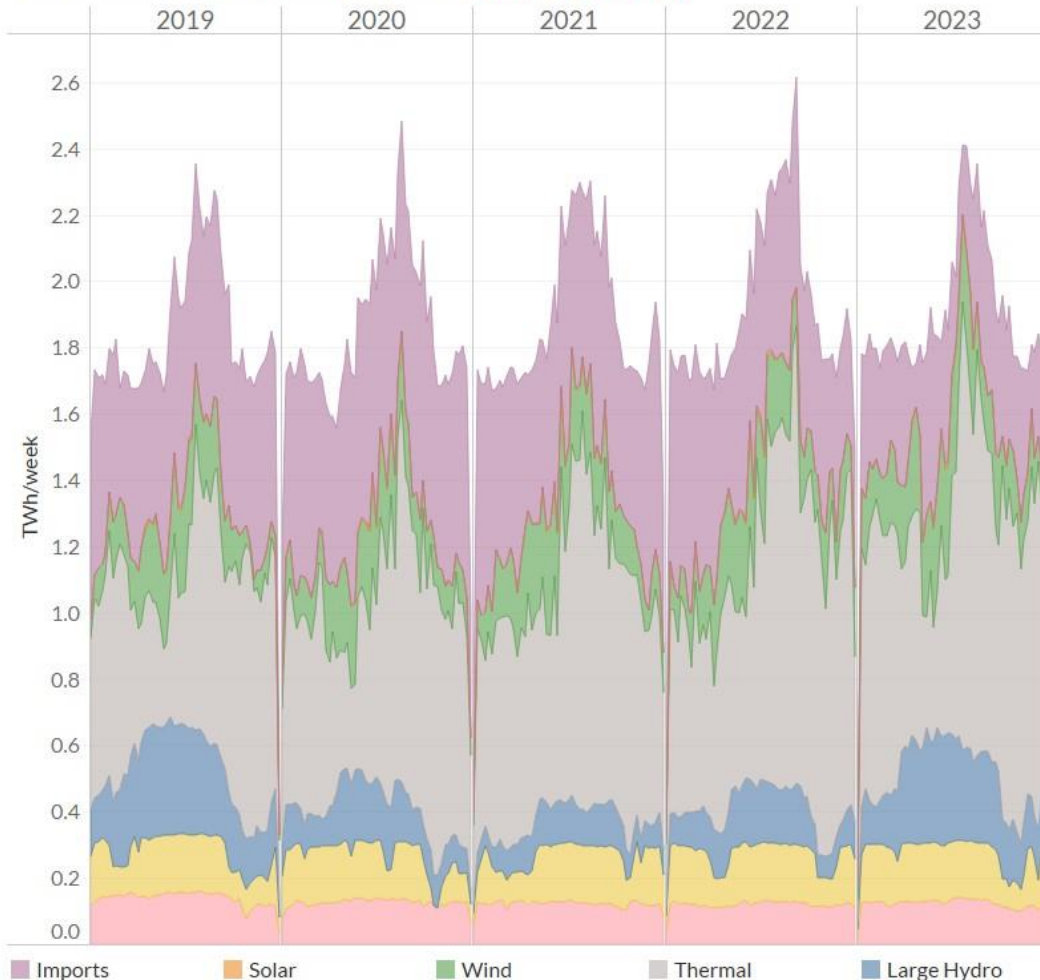
- Voluntary agreements have been reached with the Chilean government to retire coal facilities; the voluntary agreement process was started in 2018. In 2018, Chile had 5525 MWs of coal capacity. As of the end of 2023, 29% of the coal capacity available in 2018 had been retired and 66% of capacity available in 2018 is committed to be retired by the end of 2025.
- In the Chilean Climate Change Strategy defines the following goals for 2030 in the electricity sector:
 - Reduce energy emissions by 25%
 - 80% of the electricity produced should be renewable energy
- Climate change law (2022) defines the goal to achieve carbon neutrality by 2050.

California has binding goals under the SB 100

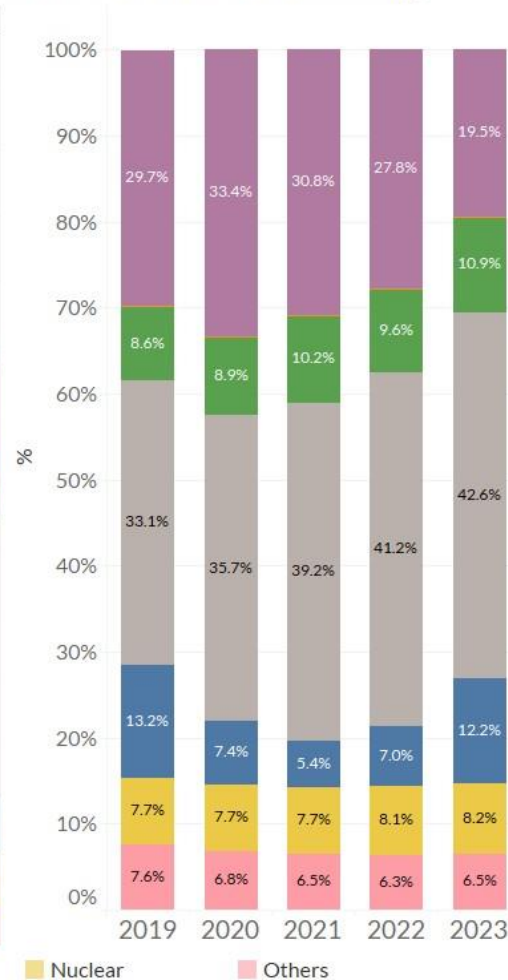
- The SB 100 sets binding goals for full decarbonization of the California energy supply by 2045.
- The SB 100 sets the stage for a full retirement or reconversion of gas generation in California by 2045, creating opportunities and challenges with reliability and system adequacy.
- It is state policy that eligible renewable energy resources and zero-carbon resources supply 100% of retail sales of electricity to California end-use customers and 100% of electricity procured to serve all state agencies by December 31, 2045.
- The bill would require that the achievement of this policy for California not increase carbon emissions elsewhere in the western grid and that the achievement not allow resource shuffling.

California & Chile are energy constrained during the night, adding wind to decarbonize the night does not ensure reliability

Weekly historical generation in CAISO by technology - Night (19:00 - 05:59 hrs)



Total Generation contribution by technology [%]



Even with a strong focus on decarbonization, in CAISO over the past four years the reliance on natural gas has increased which shows the challenges decarbonizing the nighttime, especially during the summer months.

Adding wind, does not ensure reliable supply during the night since it is highly variable. If the wind is not available, other resources will be required to supply the night.

Adding short duration energy storage will not be enough to replace the role of natural gas, other more sustainable generation sources are needed, these could include geothermal, nuclear, long duration energy storage, green powerfuels, other new technologies.

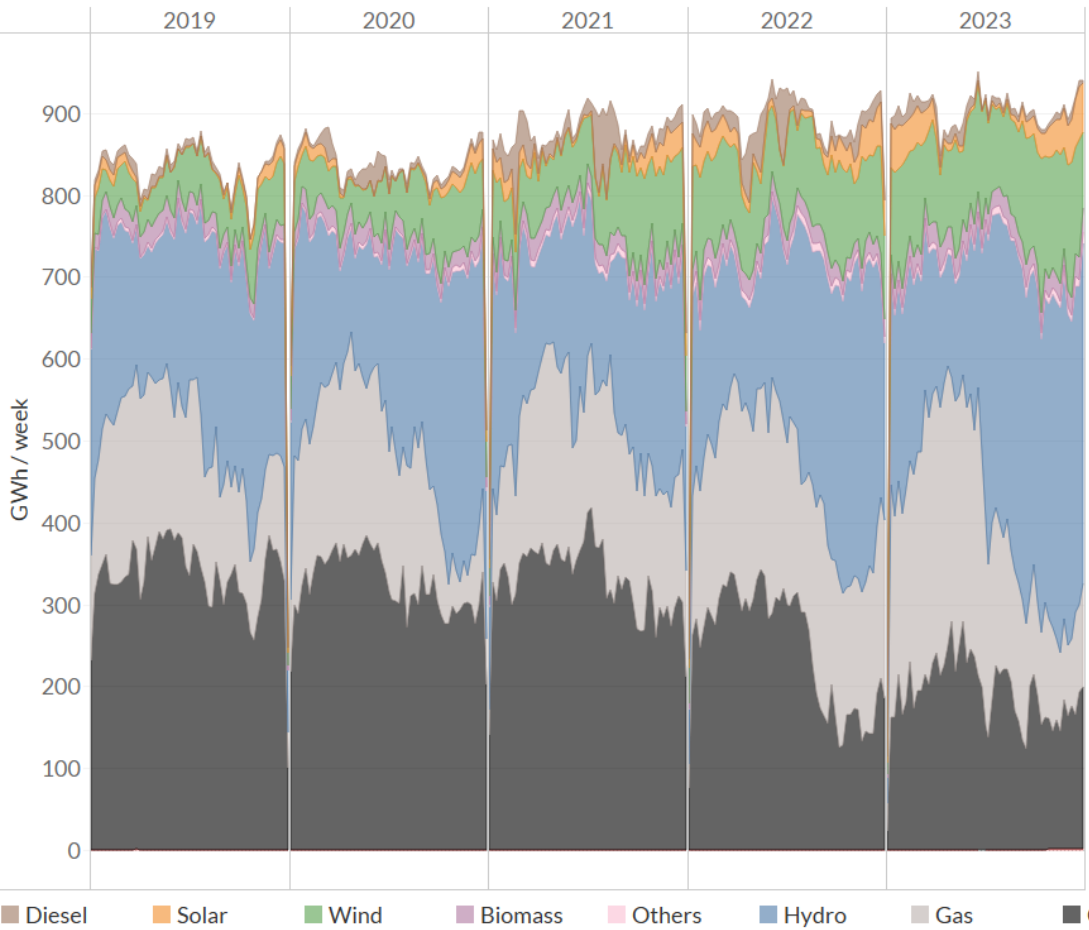
However, some of the options to supply the night are scarce, too expensive today or face social acceptance issues.

*Does not include energy storage

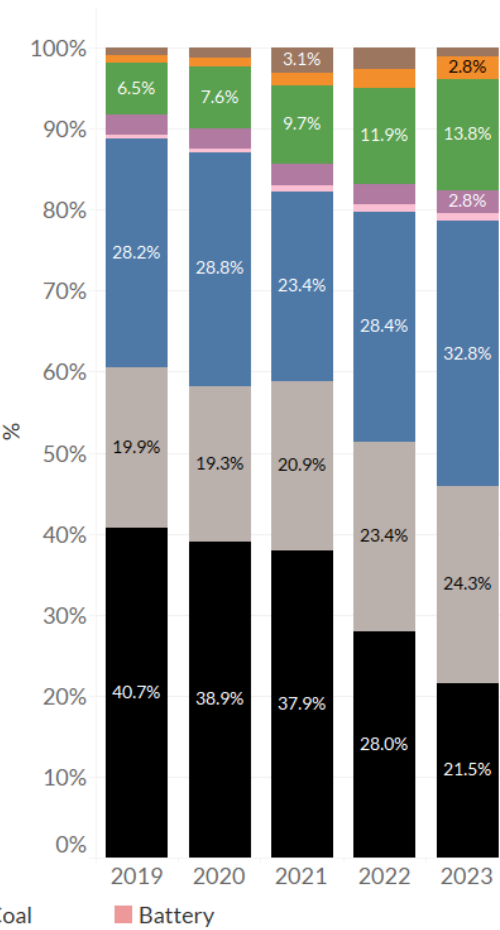
California & Chile are energy constrained during the night, adding wind to decarbonize creates challenges



Weekly generation by technology - Night hours



Total generation [%] - Night hours



In Chile, decarbonization efforts to retire coal facilities have significantly decreased the role of coal generation to supply the nighttime.

Wind and natural gas have been used to compensate for the decreases in coal generation to supply the night.

However, adding wind, does not ensure reliable supply during the night since it is highly variable. If the wind is not available, other resources will be required to supply the night.

During the fall and winter the use of natural gas has increased during the night.

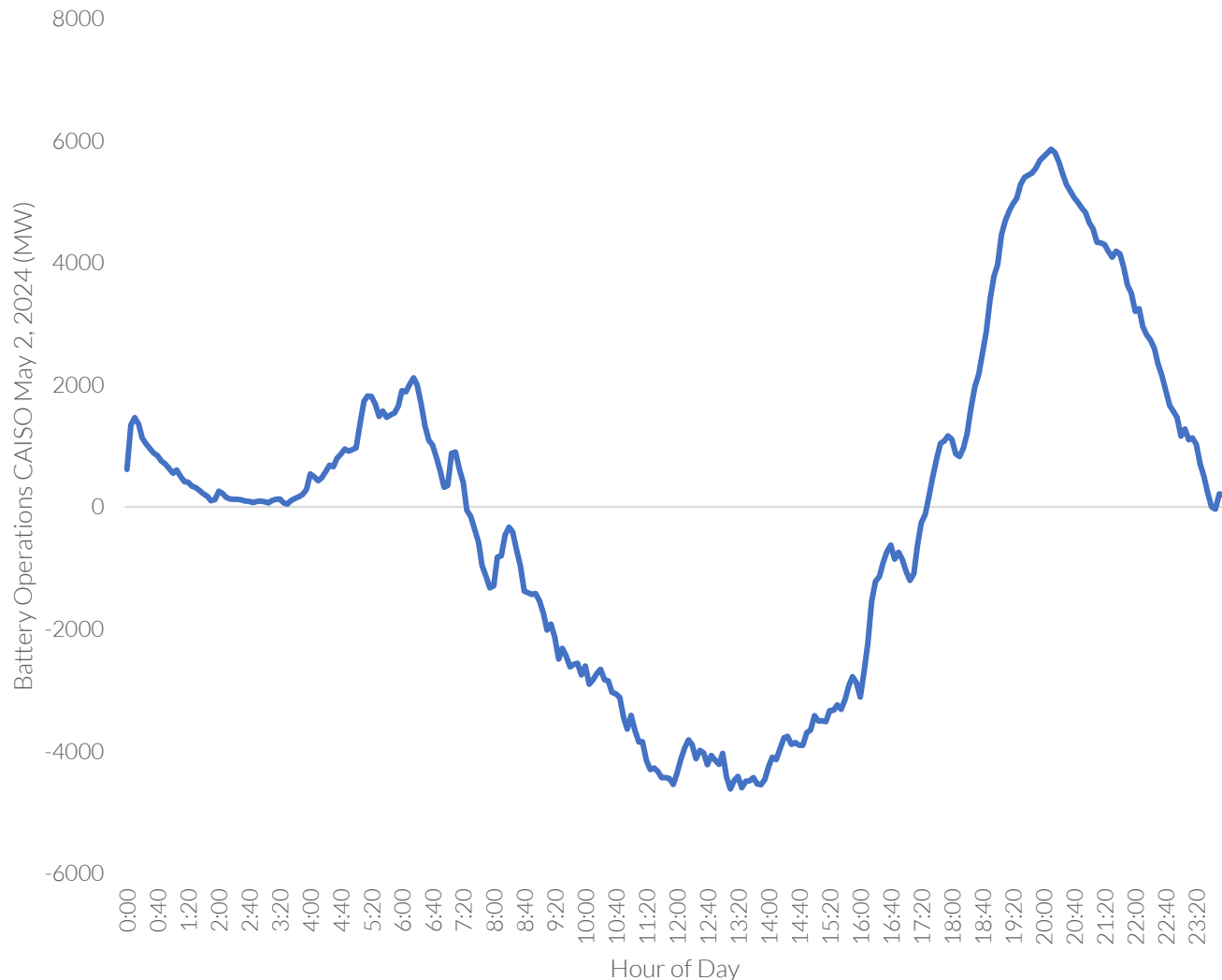
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Spot price differentials & capacity payments are creating great opportunities for batteries in Chile and CAISO however short duration batteries aren't enough to address reliability challenges



- As shown in May 2nd 2024, batteries can supply energy during peak hours and charge electricity during the day when the solar supply is highest.
- However, the operations of short duration batteries cannot address other supply needs that are required to decarbonize the system:
 - Seasonality of imports.
 - Seasonality of hydro generation.
 - Seasonality of renewables.
 - Completely remove curtailment in an efficient manner.
 - All reliability and adequacy needs.

The short duration energy storage seasonality conundrum in markets with high dependence in solar generation

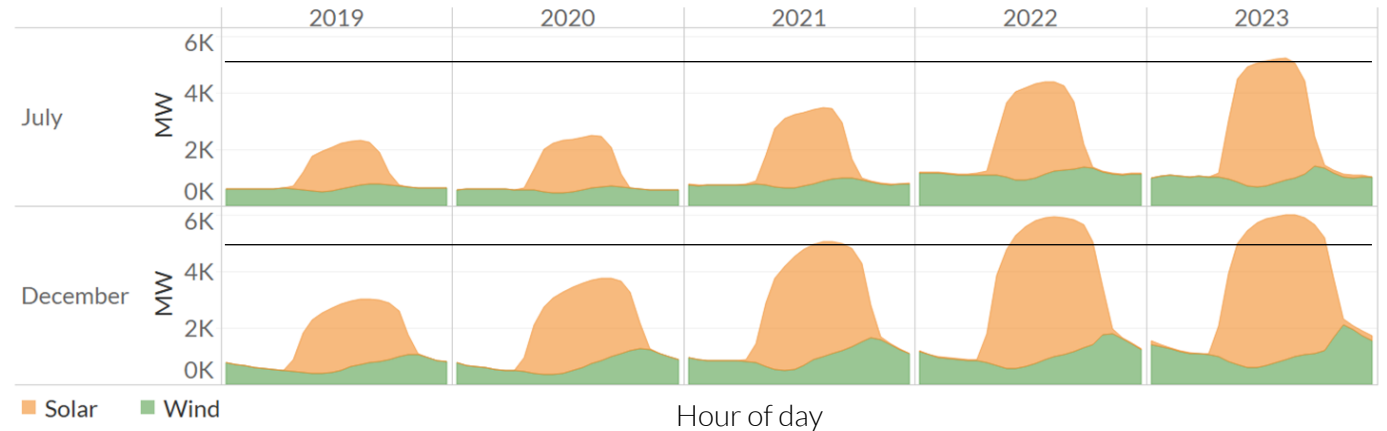
In a scenario with high utilization of energy storage, the energy storage capacity available would be determined by the renewable energy supply during the day in the winter.

However, under such scenario there would be excess energy during the day in the spring/summer and curtailment, if energy cannot be exported.

On the other extreme, a system with enough capacity to avoid curtailment in the summer/spring would be more inefficient, would lead to underutilization of energy storage in the winter and the inability of batteries to contribute to adequacy in the winter.

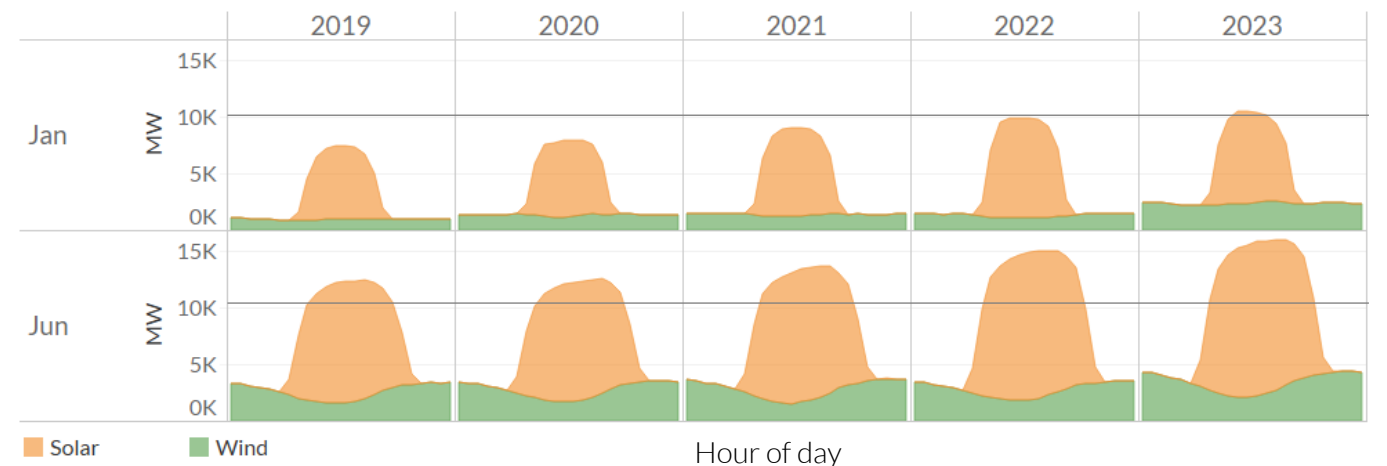
Chile

Average Renewable generation in Chile



CAISO

Average renewable generation in CAISO



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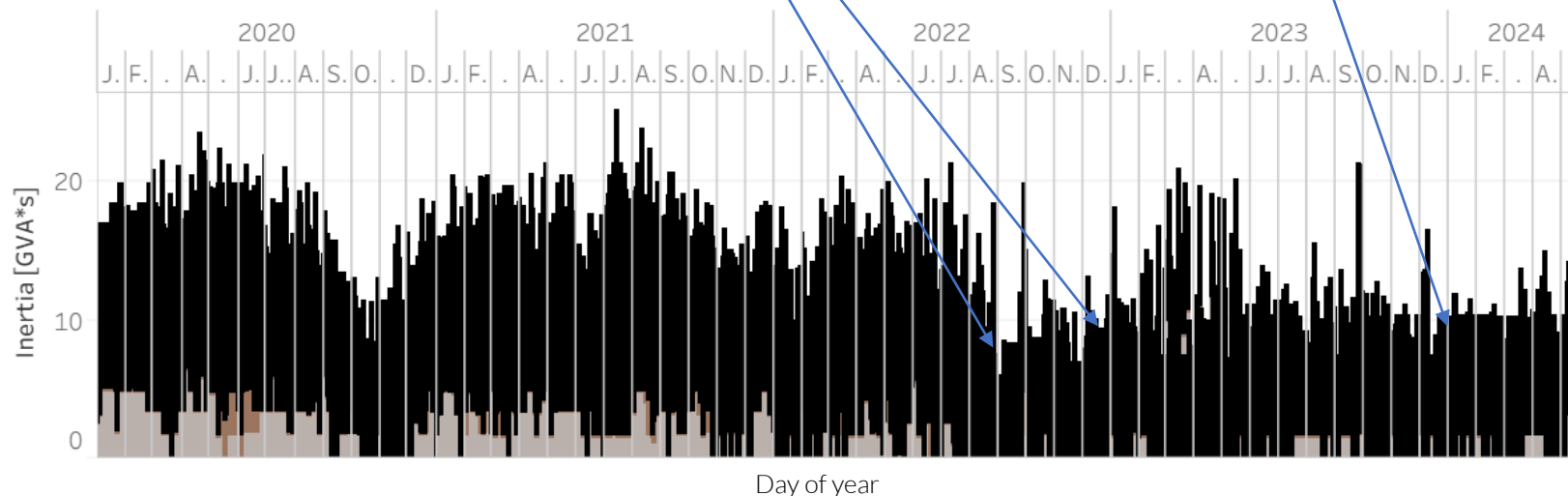


Inertia and reliability challenges can start emerging during the day and drive dispatch of other resources **inodú**

Minimum inertia levels have been decreasing in the SING reaching 6 GVAs

Minimum inertia levels occur during the day and is primarily being provided by coal units operating during the day, they are forcing dispatch of coal units to achieve these inertia levels

Estimated minimum daily inertia in North of Chile (SING)



In Chile inertia and reliability challenges are emerging in the northern region, which has significant levels of solar and wind integration. Coal and gas units are being dispatched to maintain system inertia, however, coal units are being retired.

The ISO forecasted that inertia could drop to less than 4GVAs starting in 2025, which leads to voltage stability challenges.

In their 2022 inertia study the ISO recommended operating with 7 GVAs in the NG Zone.

The ISO proposes to add 3 GVAs of inertia in 2025 and 4.4 GVAs of inertia in 2030 in the north with synchronous condensers and grid forming inverters.

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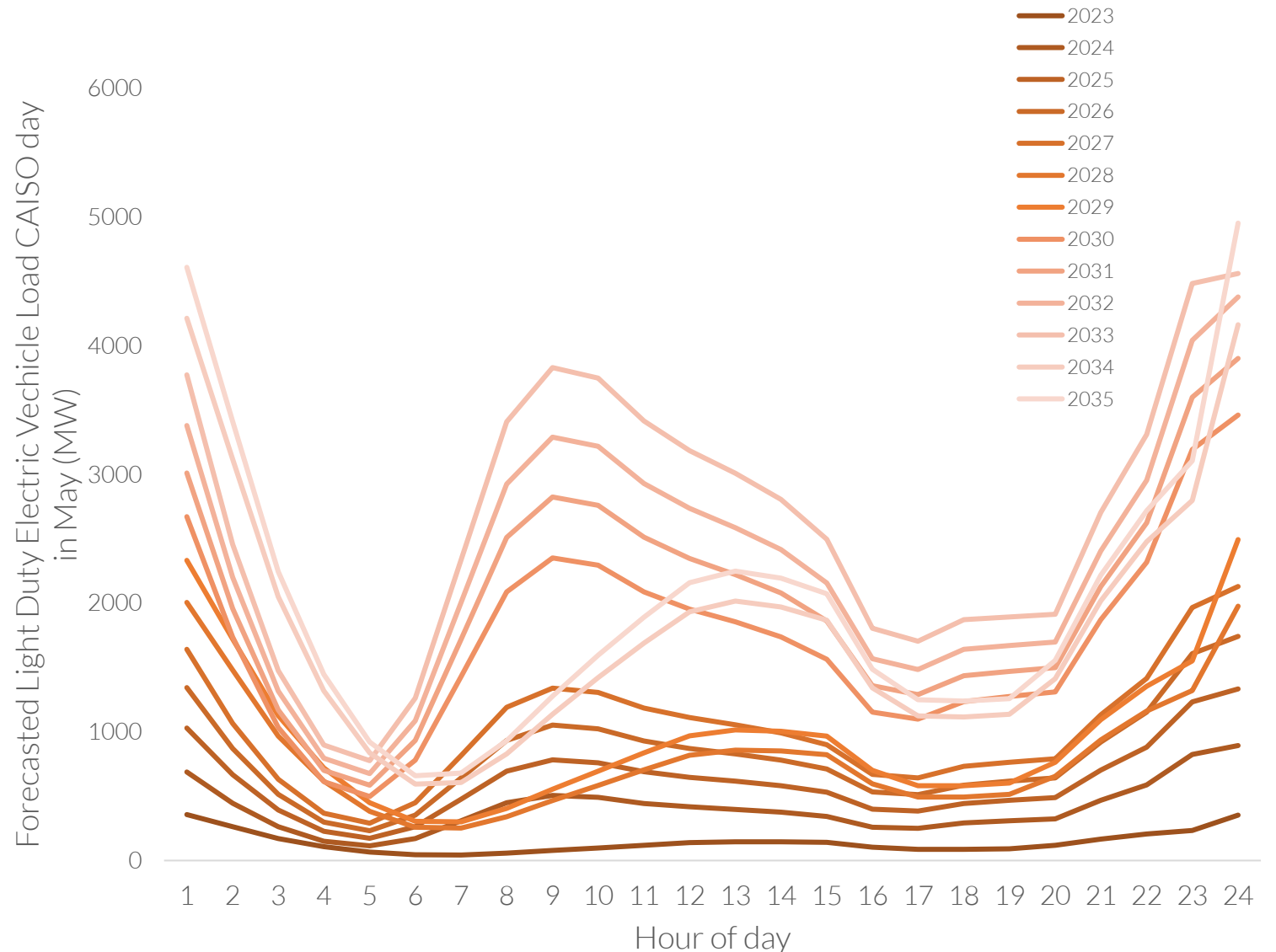
Role of electric vehicles can significantly impact capacity required in system

The storage capacity of light duty electric vehicles (LDEVs) is significant (40 kWh to 200 kWh) and can be used in different ways such as shifting load or as a battery in certain situations, assumed uses can greatly impact future utility scale capacity requirements.

Some of the definitions that greatly impact capacity expansion scenarios are:

1. Speed of adoption
2. Effectiveness of price signals for charging rates
3. Willingness by owners to allow for batteries to provide services to grid,
4. Availability of public charging stations vs. residential
5. Use of fast charging stations

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Mining and large industrial clients could have a significant impact on Chilean electricity system needs

The choices made to decarbonize diesel use in mining, supply water to mining operations and the levels of participation of large industrial clients can greatly impact the capacity needed by the power system in the future and its system operations.



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Chile's capacity recognition challenges

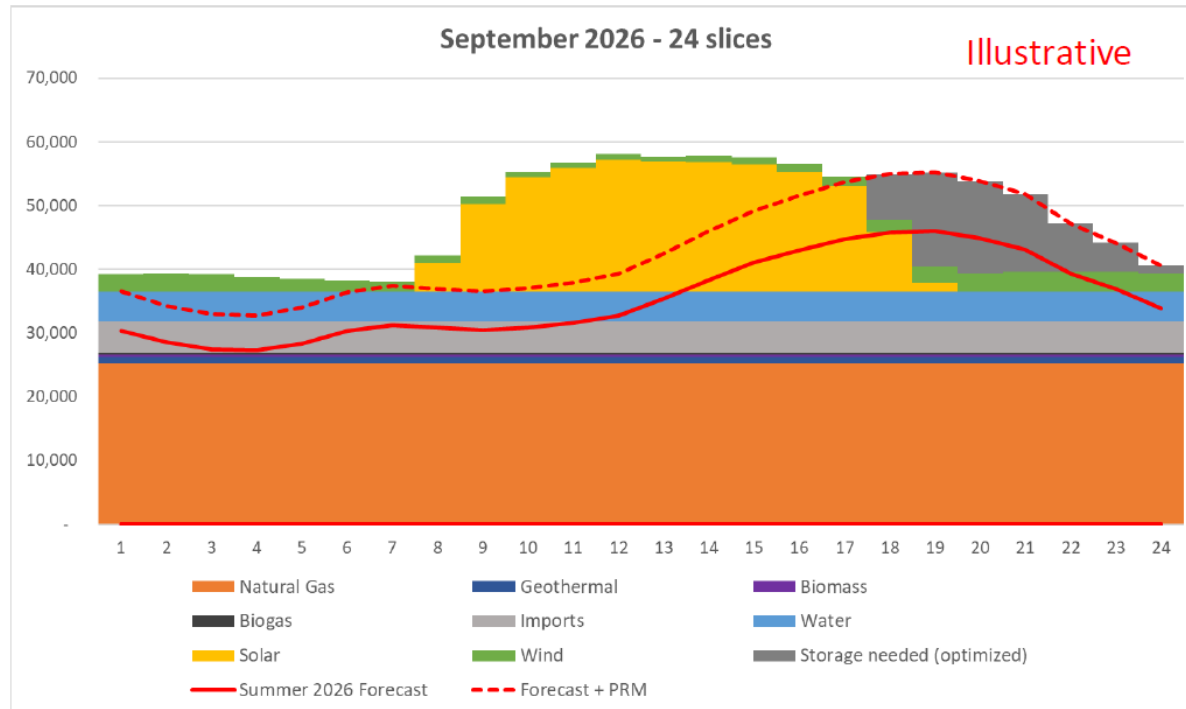
Chile has not yet addressed some of the adequacy challenges that could emerge as decarbonization efforts continue to advance.

- In Chile, capacity market reforms have been under discussion for over 4 years and the stakeholders have not reached consensus on how to move forward. Recently some adjustments were proposed to the capacity market but did not address many of the adequacy challenges that have been identified.
- New modification of the capacity recognition rules provide more certainty on the capacity recognition for energy storage and energy storage + renewable generation facilities. This should lead to more investment in short duration energy storage.
- Some of the pending challenges include:
 - How to define the contribution of storage and renewables during the most challenging periods for the system.
 - How to meet the system's potential energy supply challenges during the most challenging periods of the system as the system continues to decarbonize.

The proposed slice of day methodology in California to address system adequacy

Each Load Serving Entity (LSE) needs to bring resources to meet their Demand + PRM in all hours, with excess capacity in some hours to charge storage.

The new framework is under development by the CPUC and stakeholders but has defined the following features:



Source: CAISO Workshop



Hourly resource adequacy obligation



Storage should have the capacity to charge the energy they will discharge



Variable resource changes from a ELCC framework to an **exceedance methodology**.

The new challenge in 24/7 Carbon Free Energy is being recognized more broadly, commitments to 24/7 energy can encourage adequacy and reliability in the future.

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Collaborative action to achieve 24/7 Carbon-Free Energy

Co-ordinated by:



Definitions which affect 24/7 supply requirements in PPAs could greatly impact adequacy remuneration. Over 100 entities have signed the 24/7 Carbon Free Energy Compact.

The 24/7 carbon-free energy principles are:

- Focused on matching each hour of electricity consumption with carbon-free electricity generation.
- Purchasing clean energy on the local/regional electricity grids where electricity consumption occurs.
- Creating zero-carbon electricity systems as quickly as possible and that all Carbon Free Emissions technologies can play a role in creating this future.
- Enabling new clean electricity generation to support the rapid decarbonization of electricity systems.
- Maximizing emissions reductions and solving for the dirtiest hours of electricity consumption

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