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Market Participation Models for Energy Storage Systems in Chile

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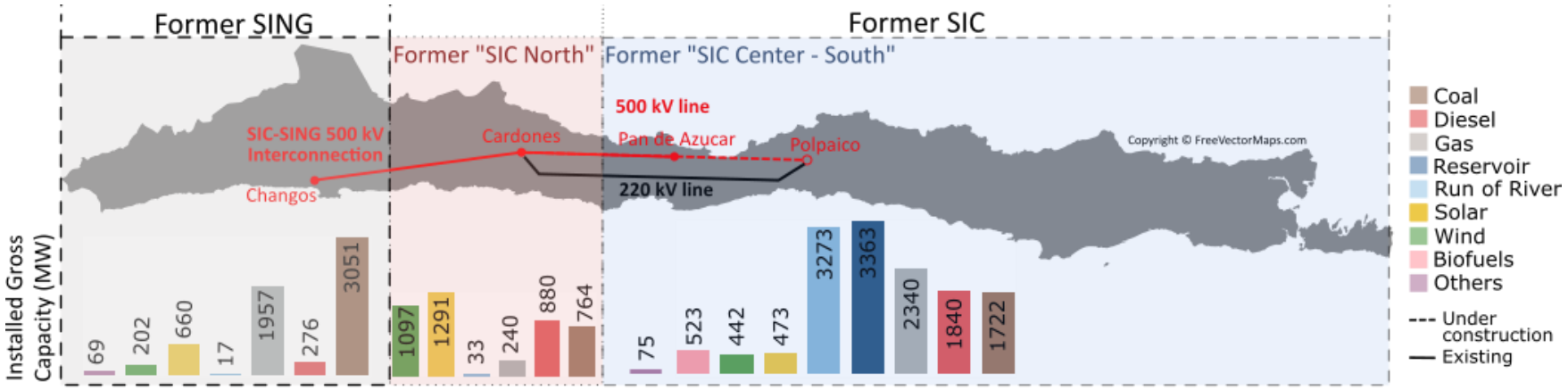
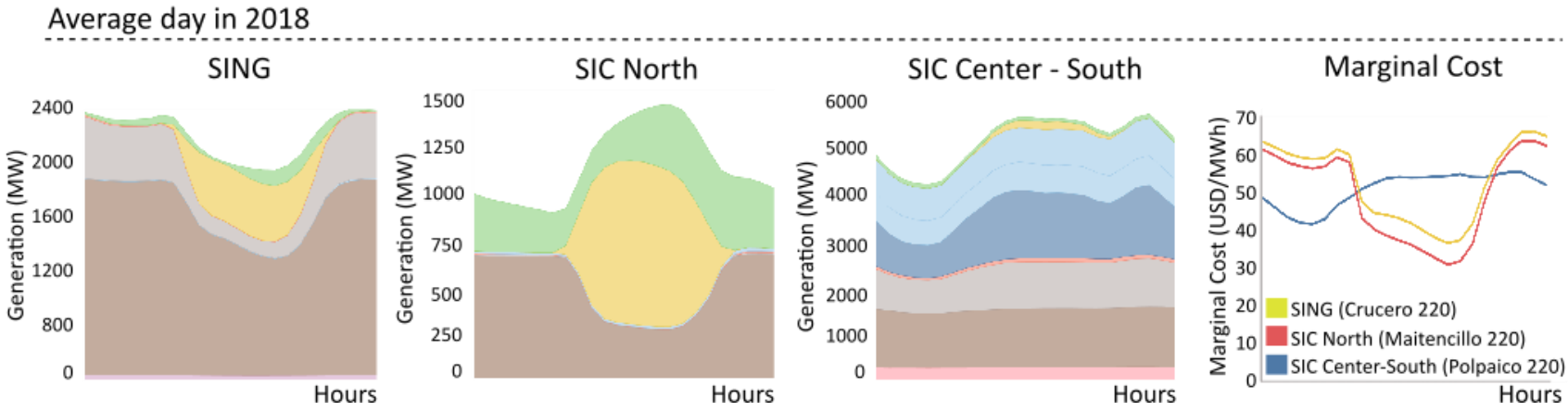
The Chilean National Electricity System (NES)





References to Energy Storage Systems (ESS) in this presentation exclude large reservoir hydropower.

An evolving generation mix

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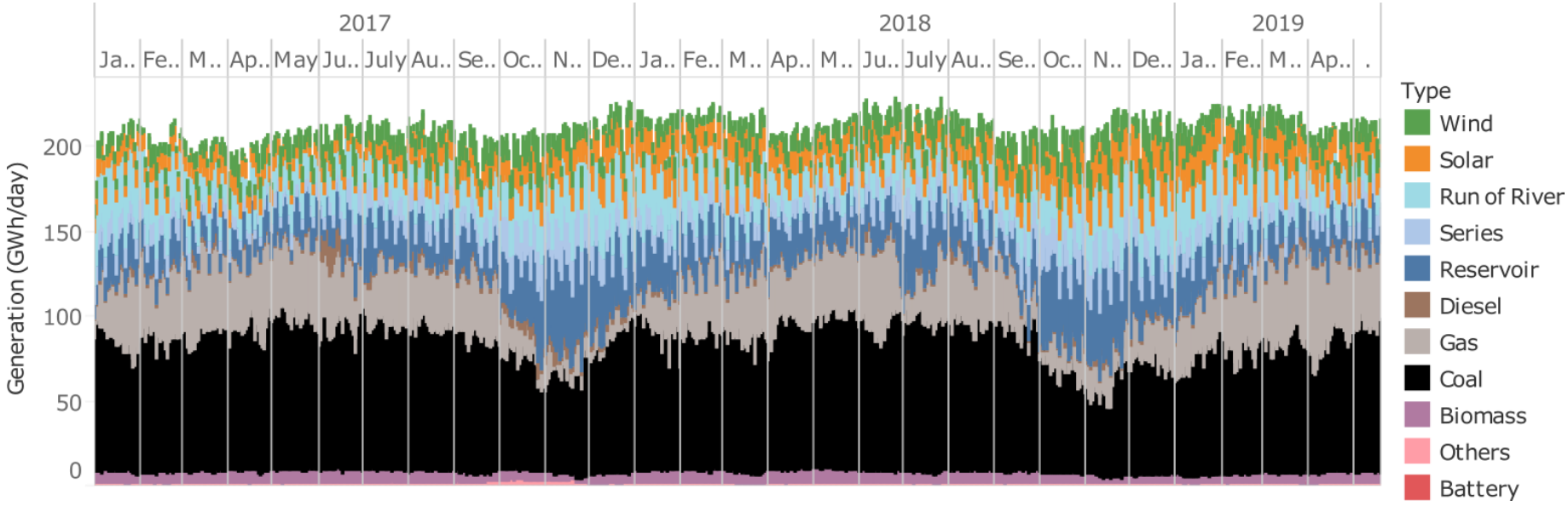


- **Solar** + **Wind** can now account for more than **20%** of the daily generation.
- **Hydro** plays a key role in providing flexibility and seasonal sufficiency.
- **Gas** and **coal** act as buffers to the changing availability of VRE and hydro.

VRE: Variable Renewable Energy, or solar photovoltaic + wind energy.

The Chilean National Electricity System (NES)

The Chilean NES is a **centrally-dispatched cost-based** system.

Units are dispatched by the system operator (ISO) according to variable production cost using a Merit Order criterion.

The Merit Order List is produced the day before during a day-ahead programming process.

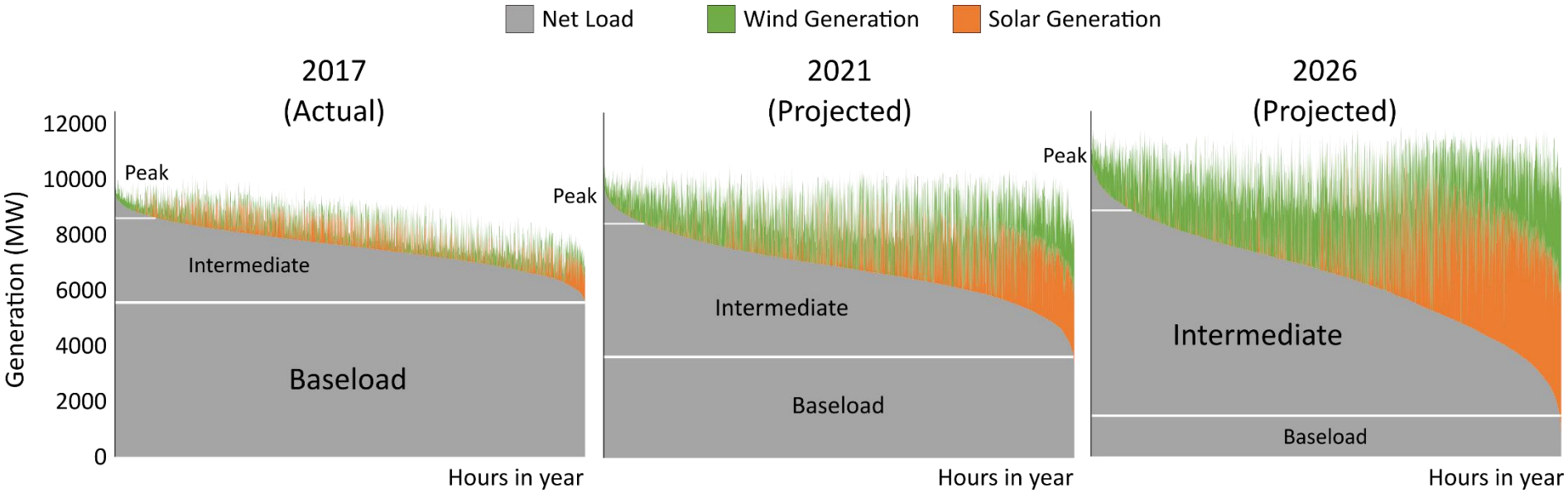
Actual spot prices are determined ex-post using operational data.

Both day-ahead forecasted prices and real-time prices are settled in 1-hour time periods.

Locational spot prices = Marginal production costs · Transmission loss factor

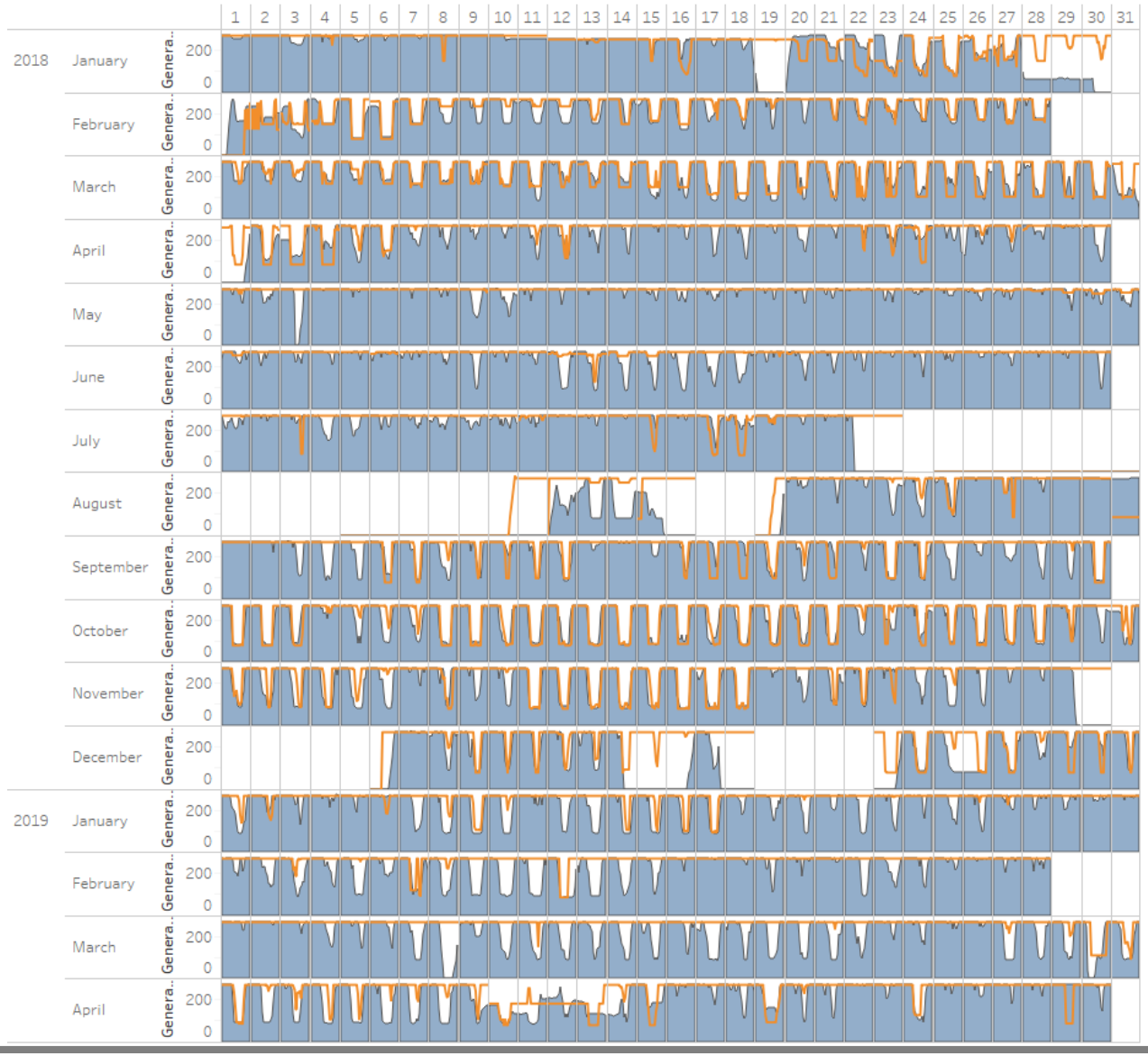
Note: Transmission congestion may create subsystems with different marginal costs.

Variability of the net load is rapidly increasing



Energy market increasingly dominated by **VRE + intermediate generation.**

Some coal power plants no longer operate as baseload



Prog. Gen.
Real Gen.

Angamos 1
Located in NES-North
Sub-bituminous coal
Capacity: 277 MWe

The minimum run level of several units has been decreased to allow higher solar PV integration.

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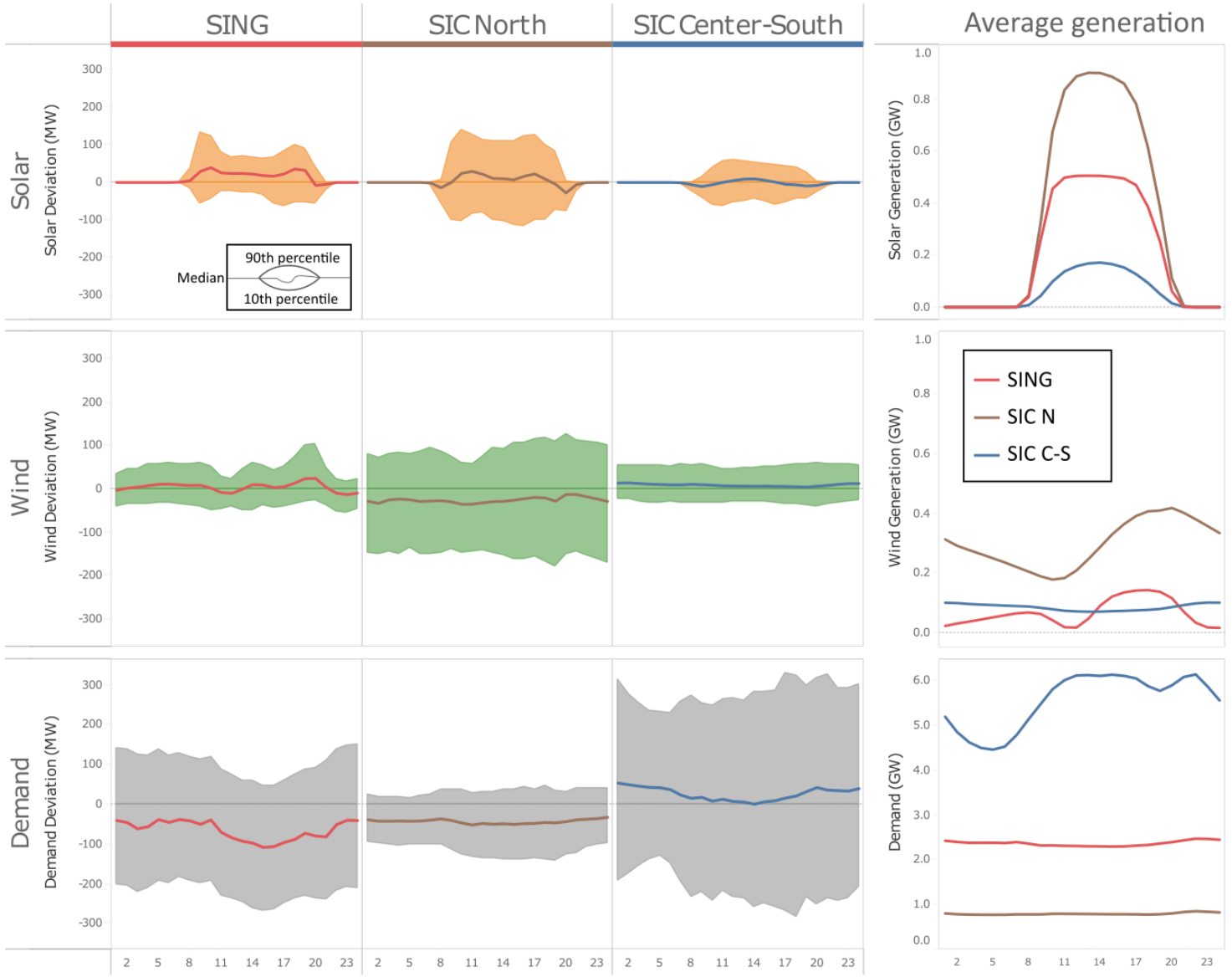
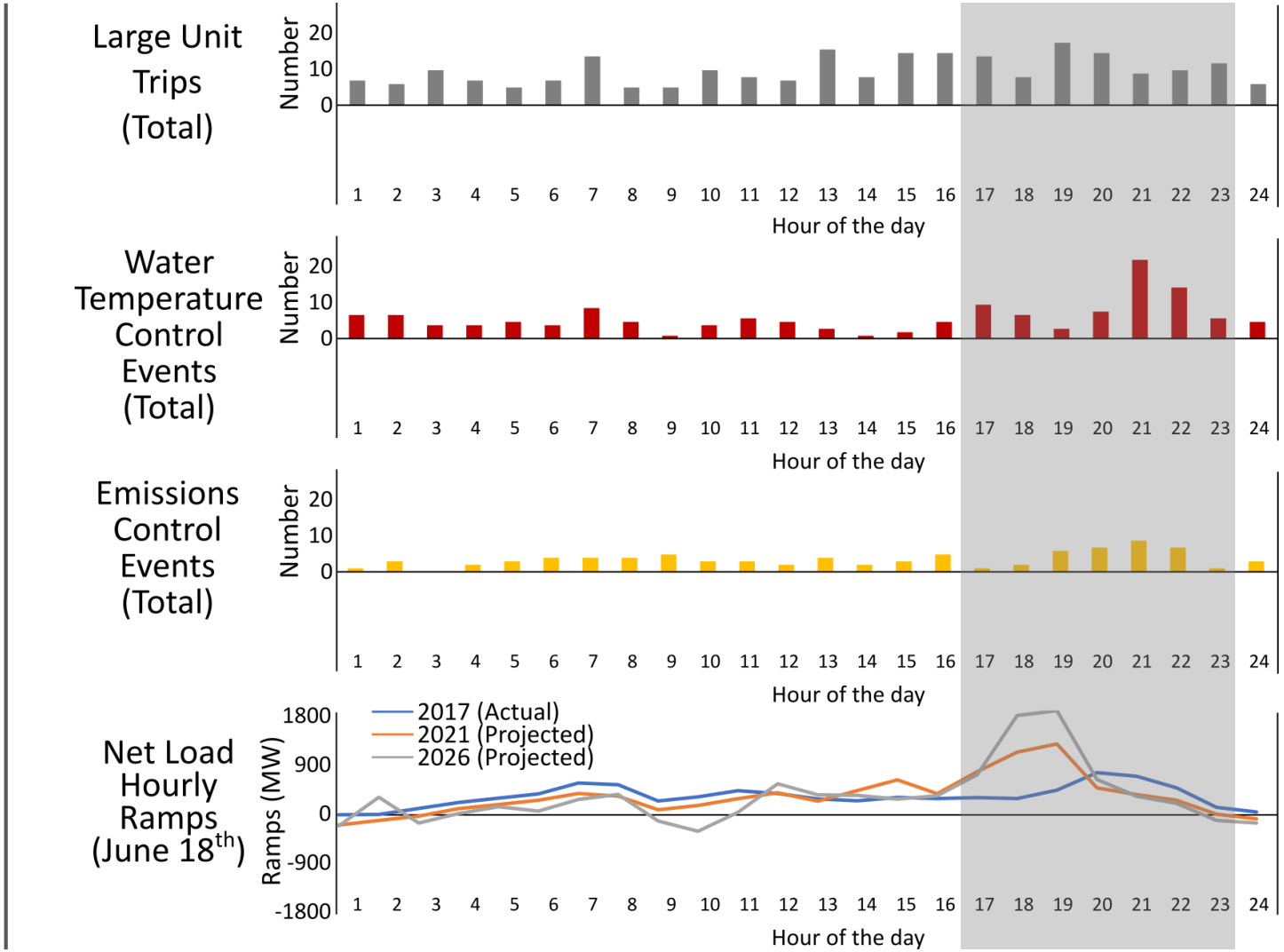
Uncertainty between day-ahead and real-time also increases

2018



New phenomena produced by VRE interact with system constraints



Impact of interacting deviations: March 13th, 2018

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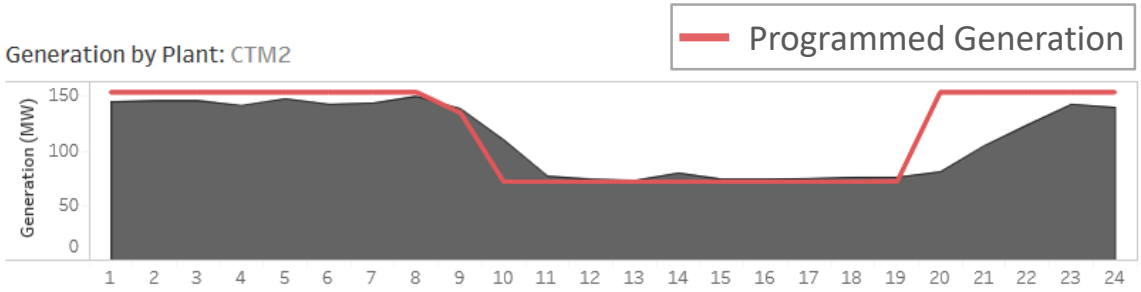
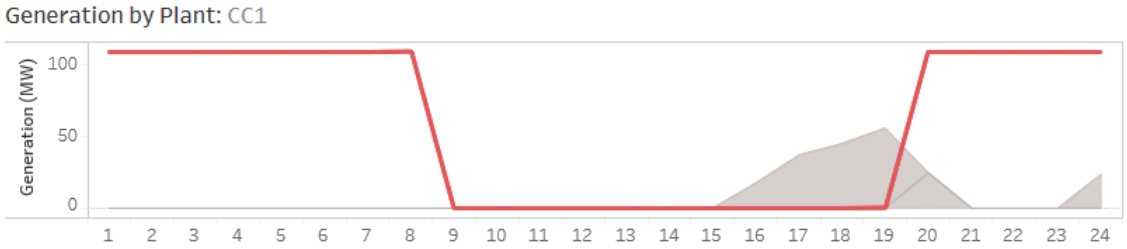
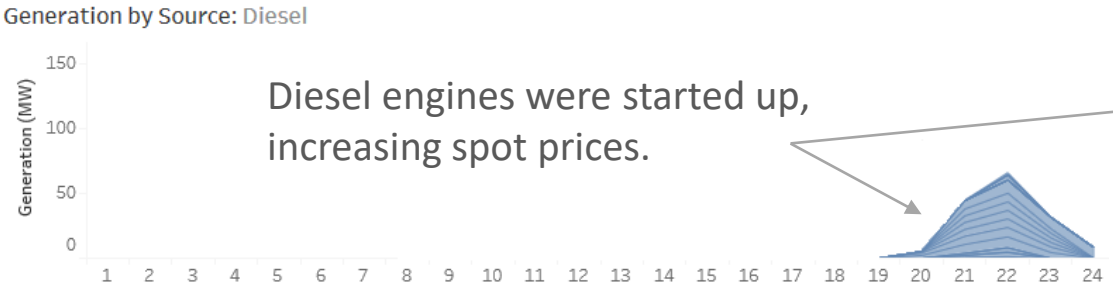


Coal plants in the NES-North were limited due to high cooling water T°.

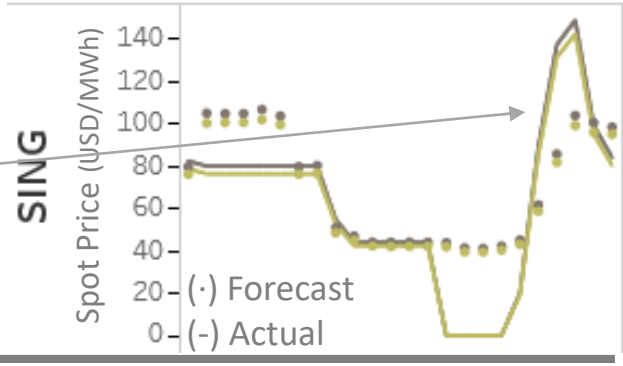


A large CCGT plant tripped.

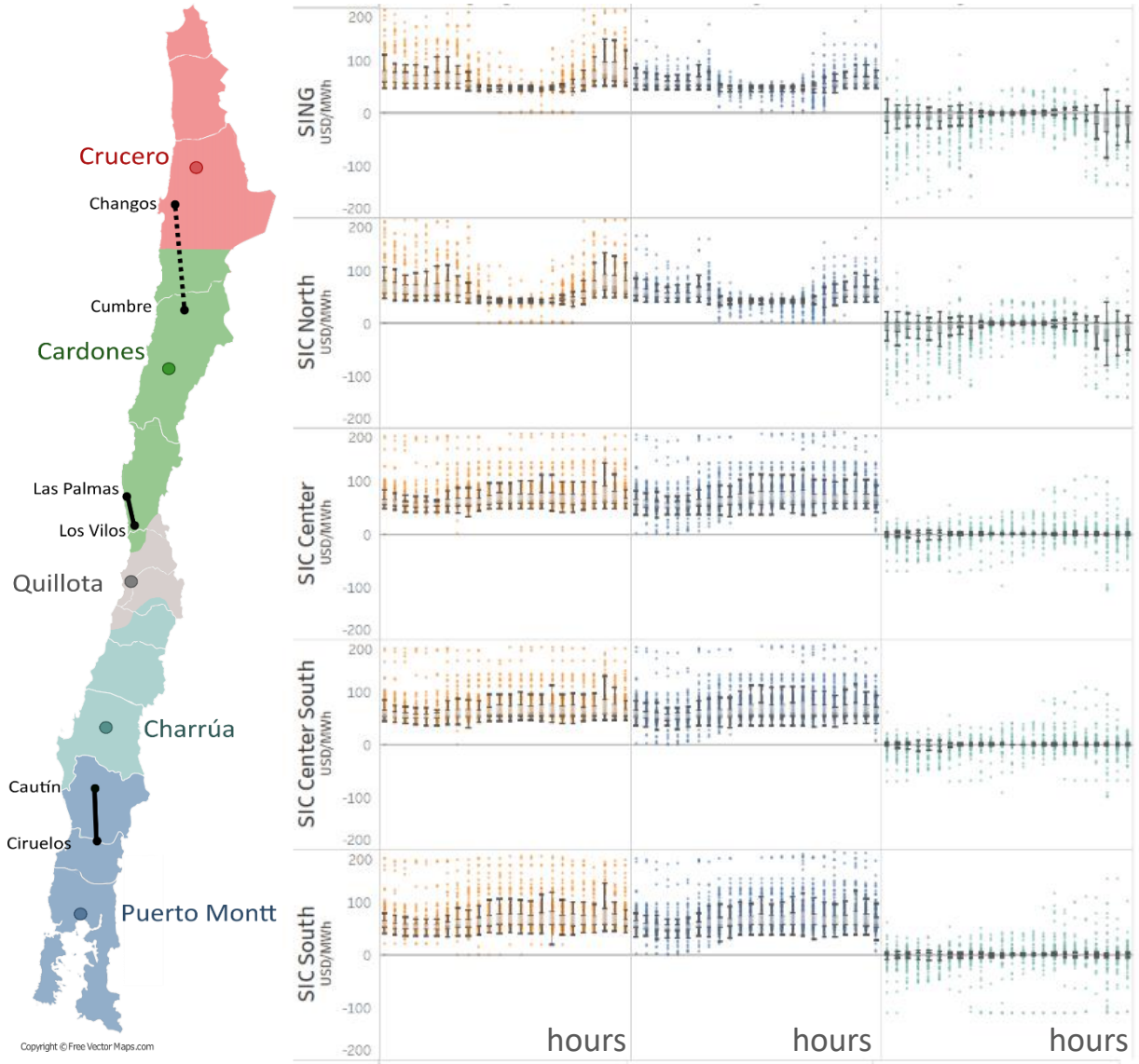
Wind plants in the North zones produced less than forecasted.



Diesel engines were started up, increasing spot prices.



Repercussions on spot price dynamics (2018)



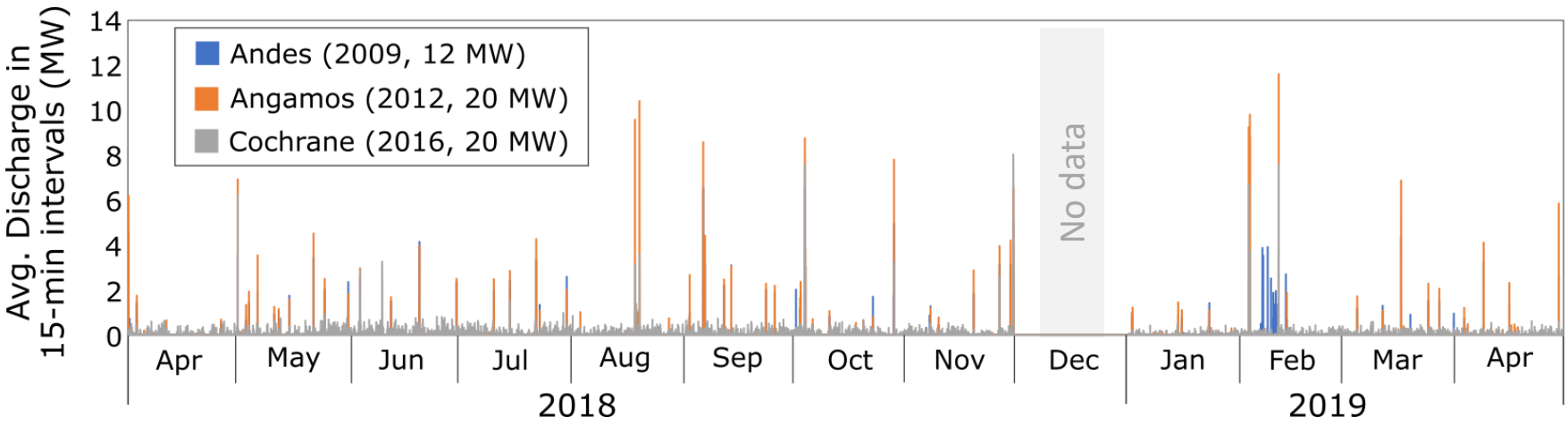
Regionalization of prices and operational challenges due to transmission congestions.

Increased spot price volatility with higher VRE integration:

- Greater variability.
- Greater uncertainty.

Rise of a challenging opportunity for **flexible assets, merchant generators** and **Energy Storage Systems**.

Operations of BESS in Chile

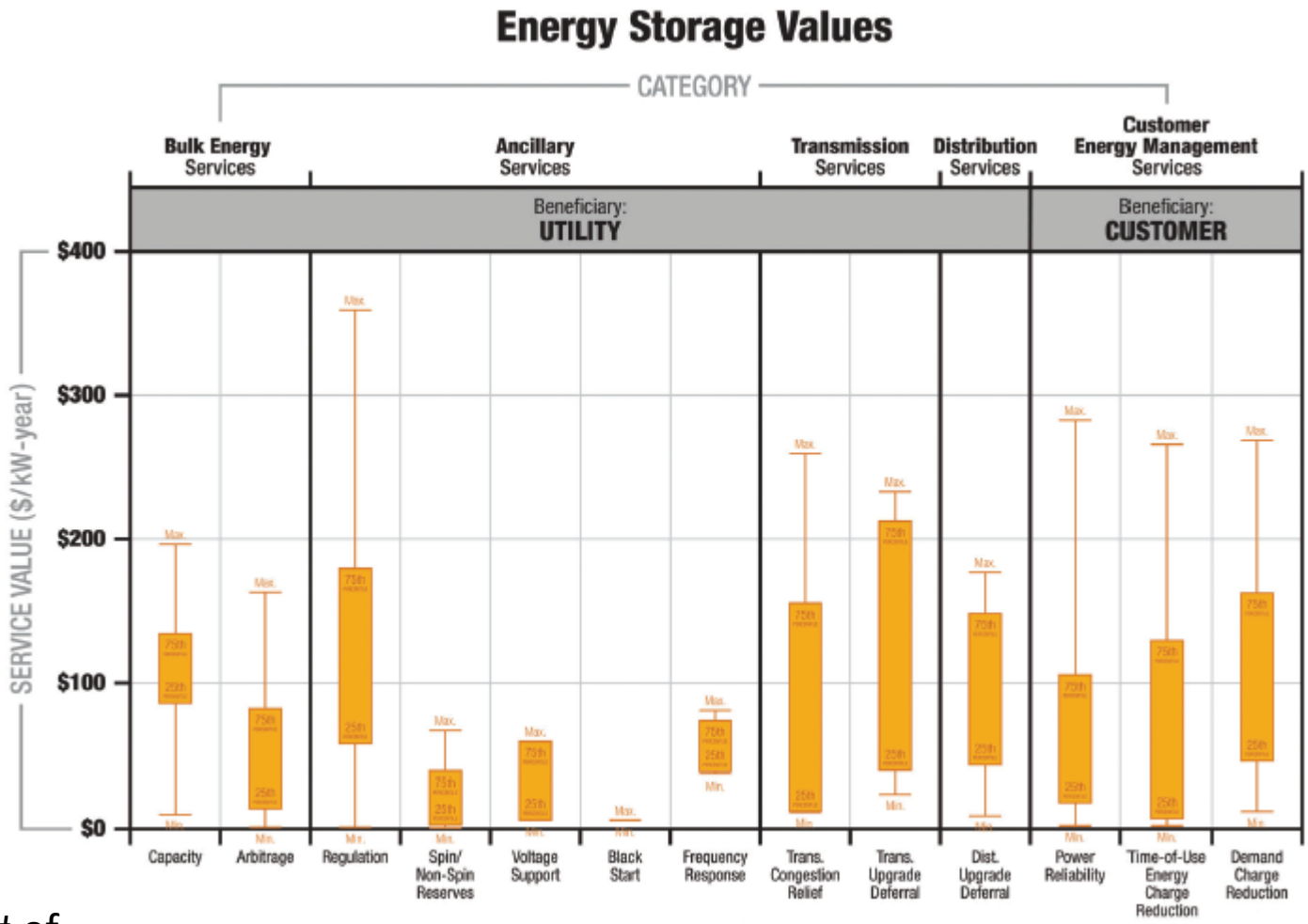


BESS originally installed by private GENCO to fulfill its coal power plants' spinning reserve requirement.

Now, used by the ISO for contingencies.

Potential new uses depend on regulatory definitions in process.

ESS have the potential to provide multiple services



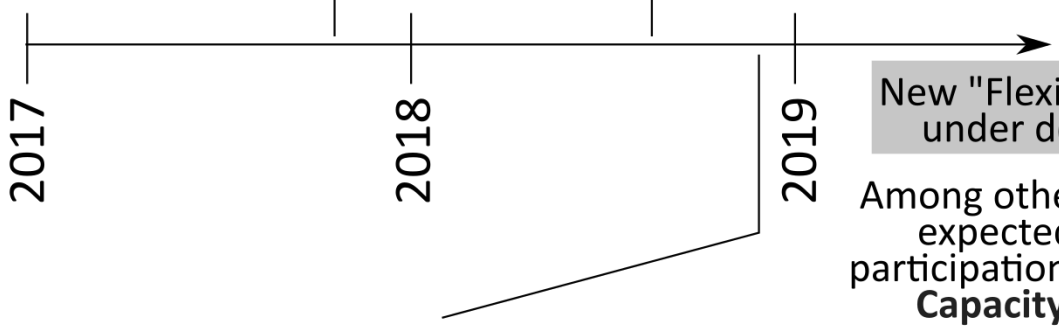
The provision of multiple services will be needed to achieve the maximum potential value of ESS projects.

Source: Balducci, P.J.; Alam, M.J.E.; Hardy, T.D.; Wu, D. (2018). *Assigning value to energy storage systems at multiple points in an electrical grid.* Energy Environ. Sci., 11, 1926.

Regulatory definitions for services from ESS in Chile

Approved Rule for **Ancillary Services (DS113/2017)**:
-Establishes a competitive auction market for provision of AASS.
-Explicitly allows participation of ESS in auctions for all AASS that these may provide.

Rule for Operation of the **Spot Market** **still in definition**:
-Attempts to define **participation models**, remuneration scheme and responsibilities for ESS.

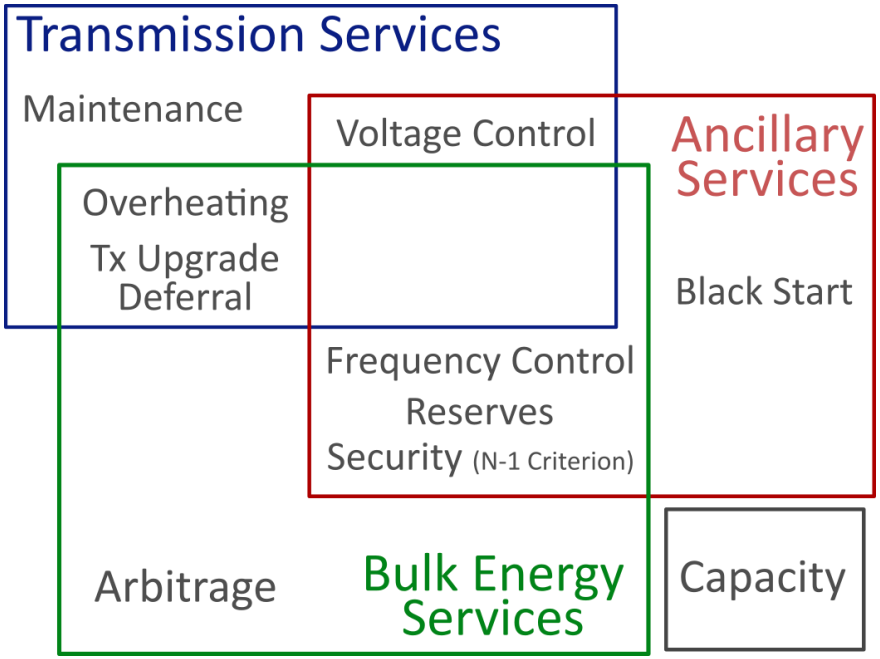


New "Flexibility Law" under definition

Among other issues, it is expected to allow participation of ESS in the **Capacity Market**.

Rule for **Transmission Systems** **still in revision**:
-Until now, allows the inclusion of ESS projects in the centralized transmission expansion plans.
-ESS projects could be included if these can economically deferr or replace transmission investments.

Why are participation models in the Wholesale Energy Market so relevant?



If not defined as a Transmission Project, investment in an ESS project would need to be recovered through capacity, energy, and AASS markets:

- AASS competitive markets can **quickly become saturated**.
- As more **VRE** is integrated in the grid, price variability is expected to increase.

Bulk energy arbitrage becomes a key source of revenue.

Proposed participation model in the wholesale energy market

DS 125/2017: Rule for Coordination and Operation of the National Electric System

(Currently withdrawn from Comptroller's office for further definitions by the Ministry of Energy)

Definitions for ESS:

- Injections and withdrawals will be valued at the Nodal Marginal Cost.
- Withdrawals will not be subject to charges applied to withdrawals for consumers: AASS, use of transmission systems, among others.
- Physical and operational characteristics considered in the day-ahead programming process will be determined by the ISO.

Some definitions are similar to FERC Order 841

Proposed participation model in the wholesale energy market

DS 125/2017: Rule for Coordination and Operation of the National Electric System
(Currently withdrawn from Comptroller's office for further definitions by the Ministry of Energy)

- Withdrawal schedule to be determined in the day-ahead and to be binding. The ISO will determine the scheduling horizon for each project.
- Injections will be determined by the ISO in real-time operations according to the variable production cost considered in the Merit Order List.

Reduction of value created by ESS that provide energy shifting

- Real-time deviations are not considered.
- Merit Order List does not allow holding stored energy until price has peaked.
- ISO to determine scheduling methodology details after project is in construction.

Proposed participation model does not take full advantage of ESS's capabilities to **maximize owner's profits** and **minimize system's operational cost**.

Contrast with regulation being implemented in the USA

FERC Order 841

Implemented to amend regulations in the Federal Power Act in order to **remove barriers for ESS** in the capacity, energy and ancillary services market operated by the RTOs and ISOs in the USA.

The commission determined that each RTO/ISO would be required "… *to revise its tariff to include a* ***participation model consisting of market rules*** *that, recognizing the physical and operational characteristics of electric storage resources,* ***facilitates their participation*** *in the RTO/ISO markets."*

Key points relevant for Chilean regulatory definition process:

- Gives storage resource owners the right to **manage their own state of charge**.
- ISOs must represent the physical and operating **characteristics of storage** through bidding parameters or other means.
- Ensures that ESS will be eligible to provide all **capacity, energy, and ancillary services** that the resource is technically capable of providing.
- Allows storage resources to be eligible for **make-whole payments**.

Provides more **certainty** to investors.

Experiment: Potential energy arbitrage profit of a BESS project

Model to estimate the annual profit obtained by a BESS through 5 different energy arbitrage strategies using real 2018 spot prices in the Chilean market.

Proposed Participation Model in Chile

(DS 125/2017)

Withdrawals scheduled **day-ahead**.

Energy is injected by the ESS into the grid when determined by the Merit Order List.

How would a BESS operate under the proposed scheme?

3 Experimental Participation Models

3 different dispatch strategies are simulated.

Proposed strategies consider data signals made available in the Chilean spot market by the ISO.

- Day-ahead price forecast.
- Online estimated price.
- Real-time prices published after 3 days (on average).

Could a BESS obtain a higher profit if the owner operated it?

Maximum Potential Profit

Maximum potential profit is calculated considering **perfect forecast** of real-time prices.

How do different schemes compare to the optimal dispatch?

Methodology

Packages: Pyomo & Pandas
Solver: CBC
Linear program.

Optimal dispatch model for a **price-taker** BESS set up in Python.

- Maximizes profit for each day (considers 2-day look-ahead period).
- Max and min state of charge.
- Max rates of charge and discharge.
- State of charge tracking.
- Charge and discharge efficiencies.

Parameters are considered independent of state-of-charge.

Simulated dispatch models:

Optimal: Dispatch is optimized considering **perfect foresight** of spot prices.

Merit List (Proposed Rule): Withdrawals optimized using **day-ahead forecast**. Offer price is updated hourly according to withdrawal costs. Energy is discharged when $\mathbf{MgC_{BESS} <= MgC_{System}}$

Day-ahead: Dispatch (withdrawal & discharge) is scheduled using **day-ahead price forecast.**

Real-time Heuristic: Withdrawals occur when estimated real-time spot price falls below a threshold and is discharged when the price climbs above the upper threshold.

Day-ahead & Day-before: Dispatch is scheduled using an **average** of **day-ahead** price forecasts and **real prices** from the **previous day**.

Methodology

Packages: Pyomo & Pandas
Solver: CBC
Linear program.

Optimal dispatch model for a **price-taker** BESS set up in Python.

- Maximizes profit for each day (considers 2-day look-ahead period).
- Max and min state of charge.
- Max rates of charge and discharge.
- State of charge tracking.
- Charge and discharge efficiencies.

Parameters are considered independent of state-of-charge.

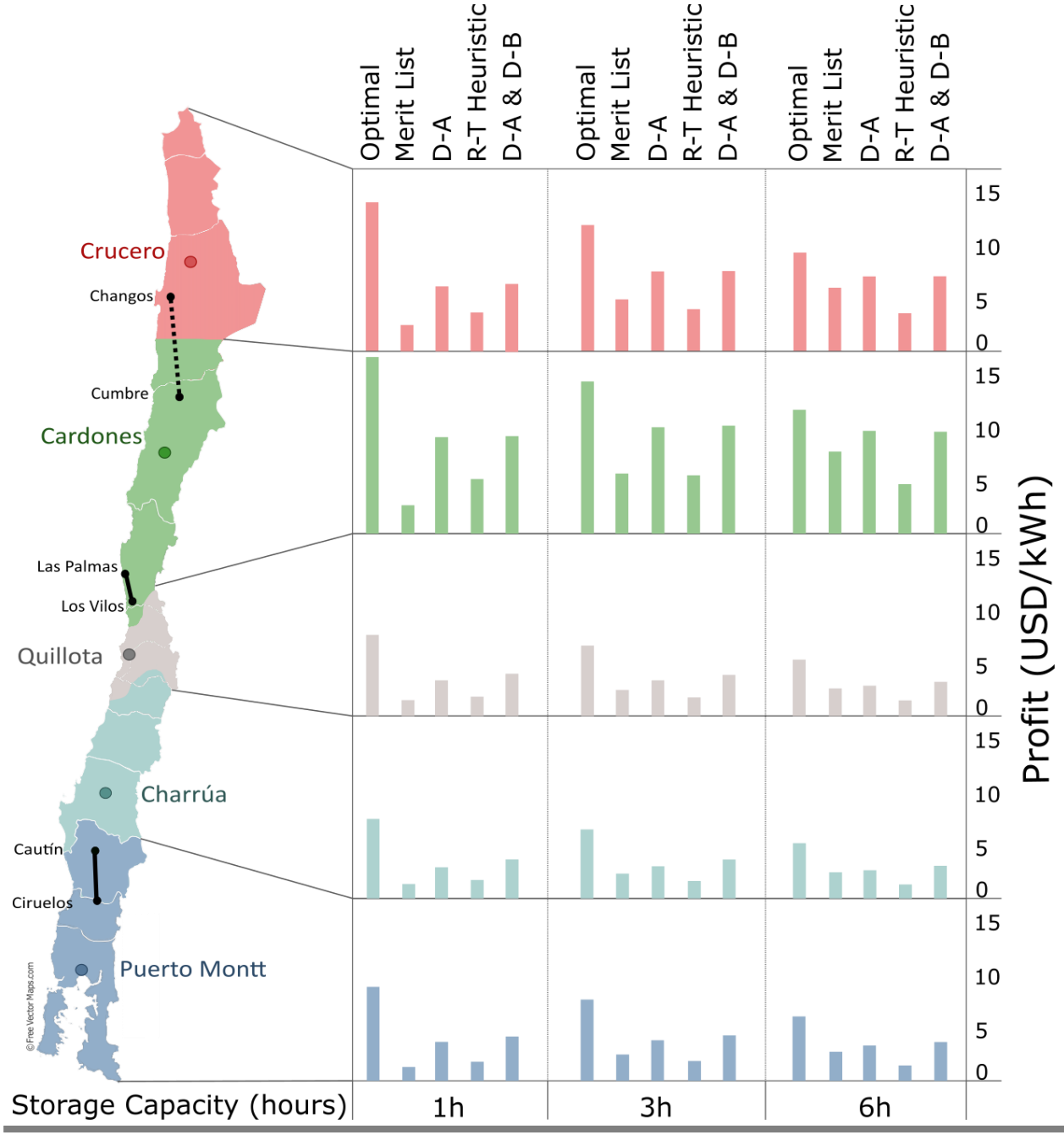
Hourly forecasted and actual prices of **2018** were used.

Sensitivities	**Location**: 5 nodes **Duration**: 1, 3, 6 hours

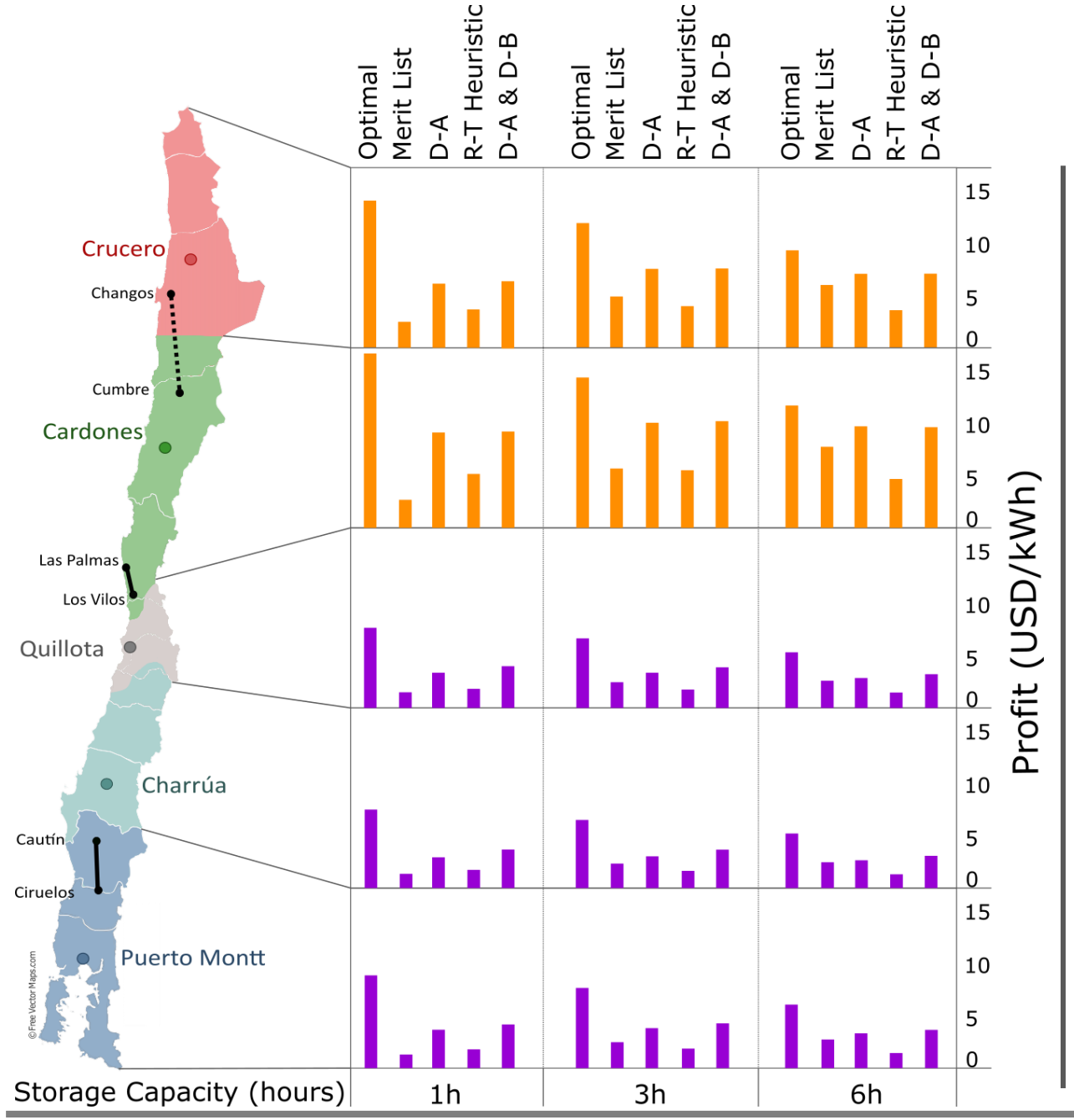
An additional sensitivity for the **Optimal** dispatch is performed:
Reducing the price settlement period from **1-hour** to **5-minutes**.

Results

$\eta_c=\eta_d=0.95$
1 MW



The total profit per installed kWh of storage is shown for the simulated year (2018).



Results

$\eta_c=\eta_d=0.95$

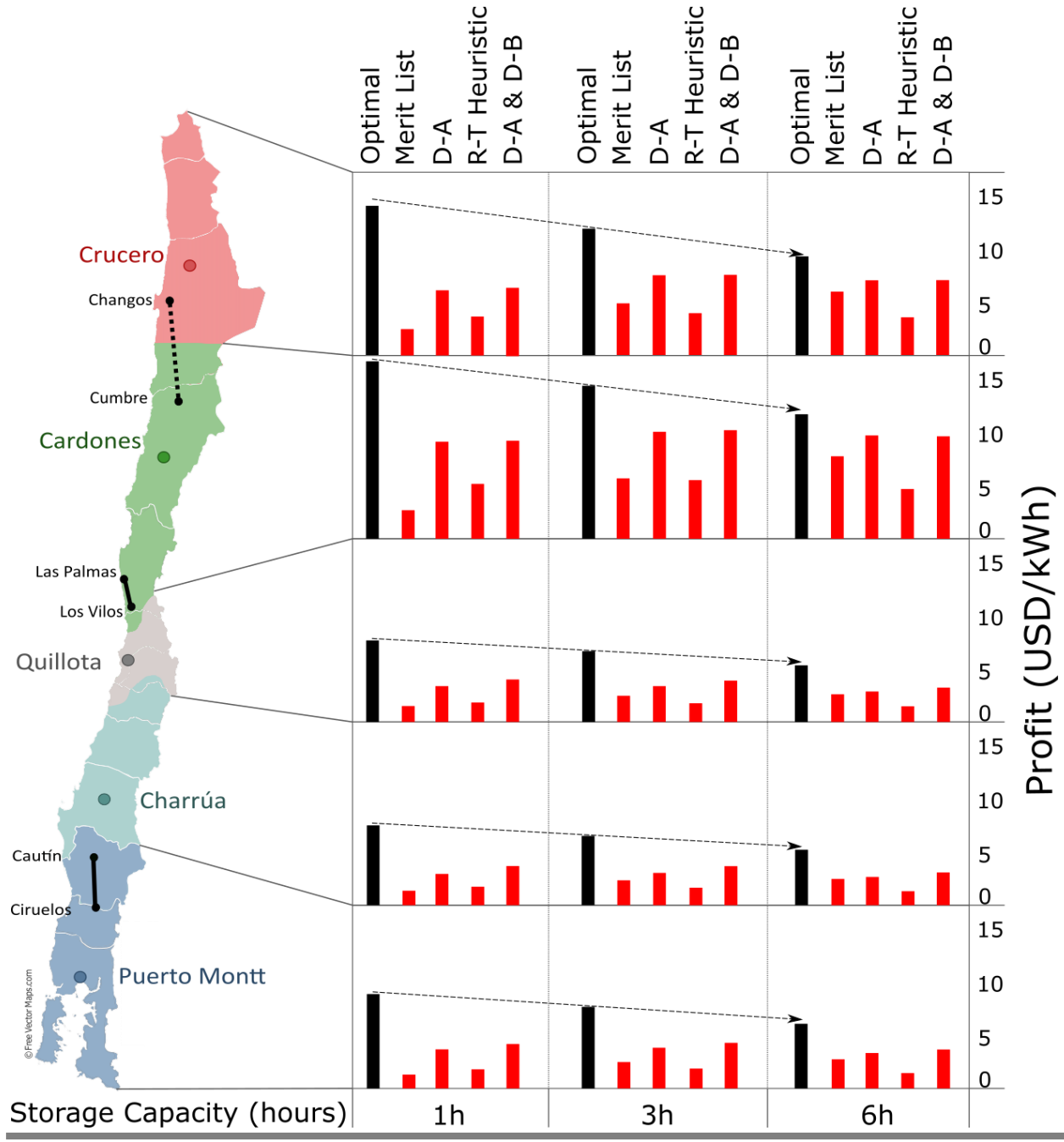
1 MW

Potential profit in the **NES-North** is observed to be 2-3 times that in the **NES-South**.

- Revenues captured by BESS heavily depend on intra-day price variability.
- Hydro reservoirs are strong competitors in the flexibility market.

Results

$\eta_c=\eta_d=0.95$
1 MW



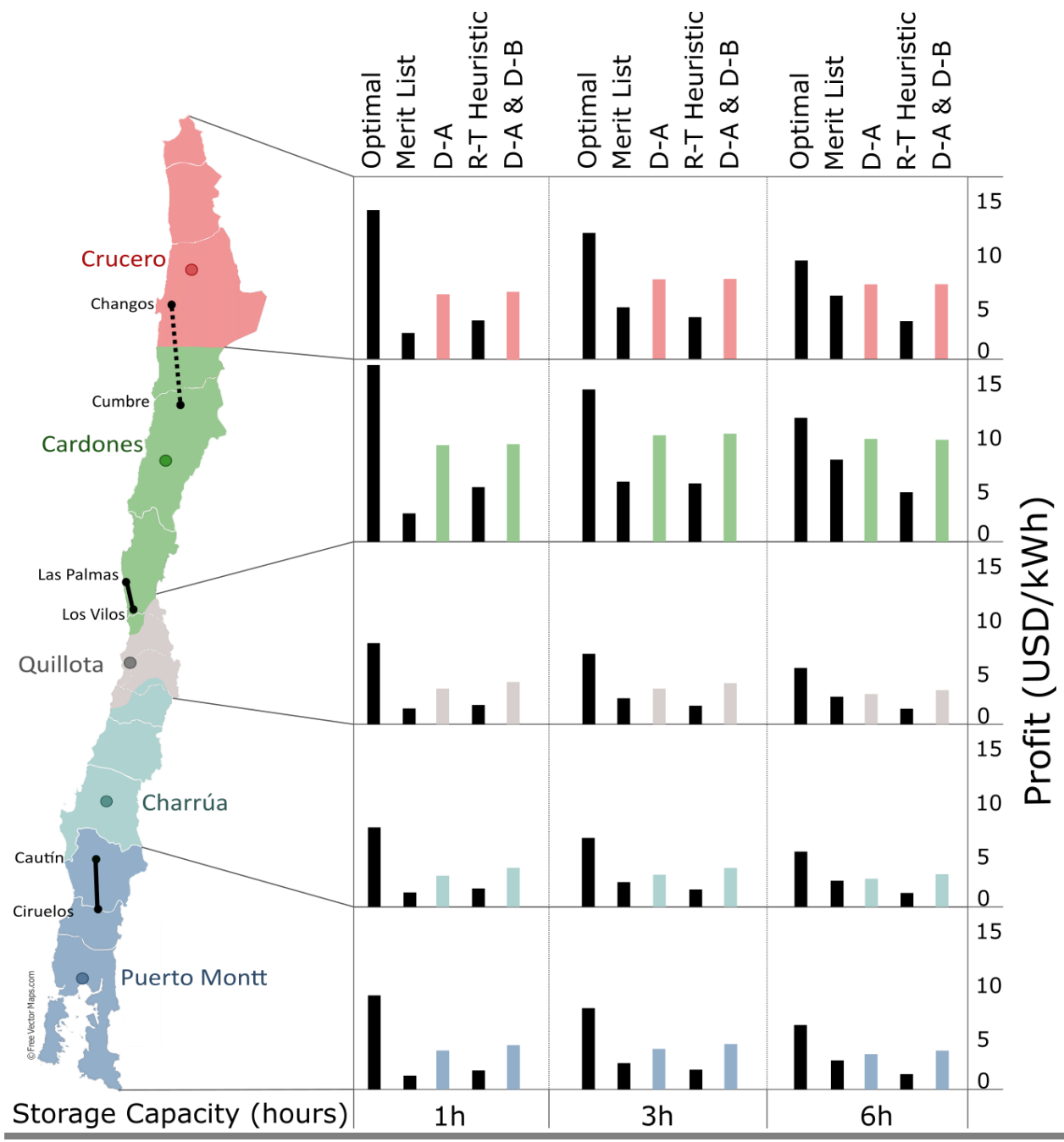
Potential profit in the **NES-North** is observed to be 2-3 times that in the **NES-South**.

- Revenues captured by BESS heavily depend on intra-day price variability.
- Hydro reservoirs are strong competitors in the flexibility market.

Potential profit per installed kWh decreases with higher storage durations, though all strategies are able to capture higher proportion of potential maximum profits.

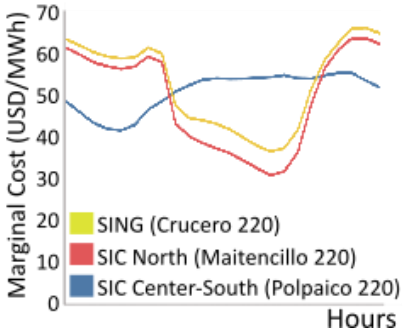
Results

$\eta_c=\eta_d=0.95$
1 MW



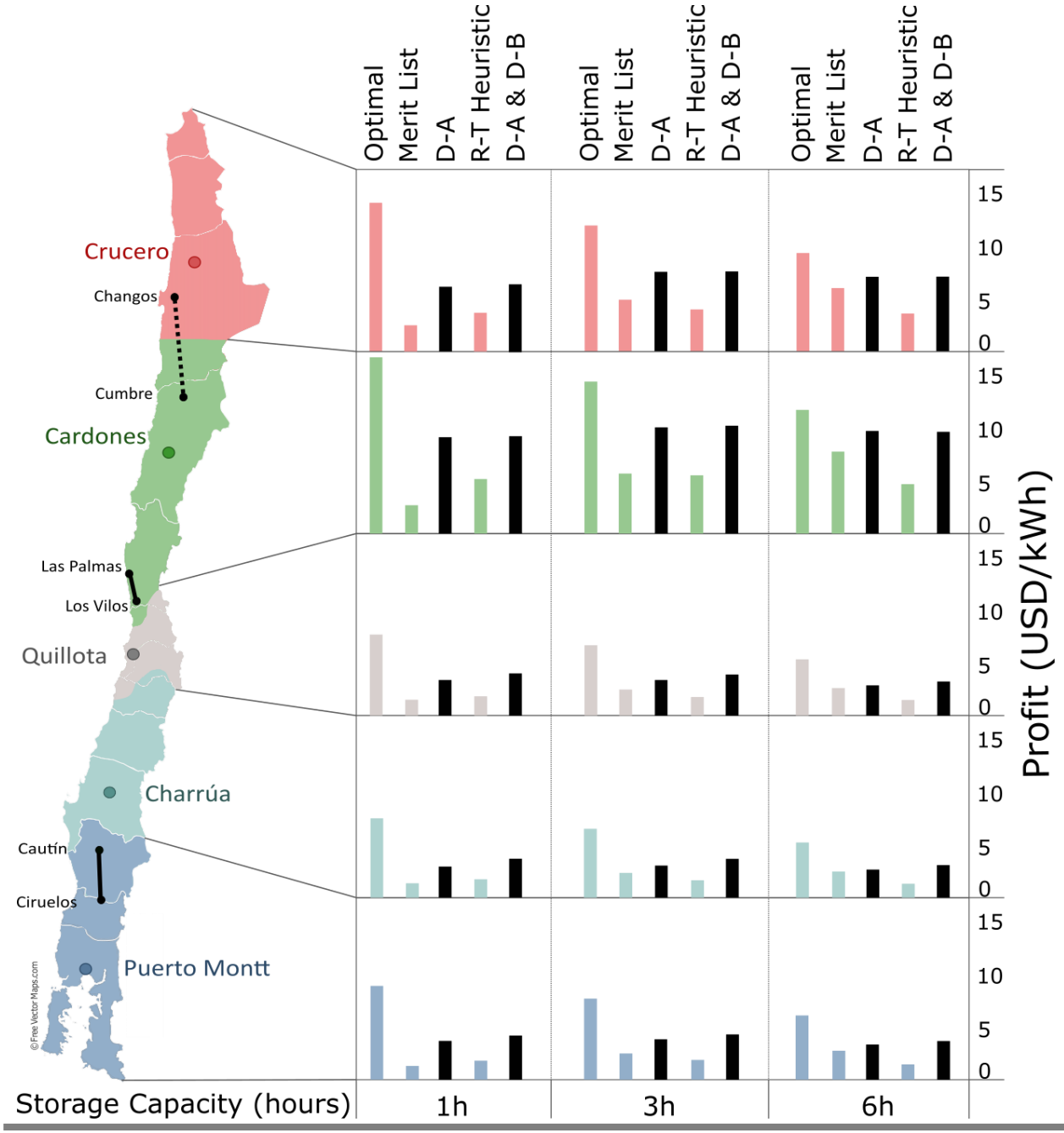
The **Merit List** and **Real-time Heuristic** strategies for energy injection are found to capture a smaller portion of potential profit.

- Merit List fares significantly better for larger storage durations.
- Merit List yields better results for a BESS in the NES-North, due to price curve shapes.



Results

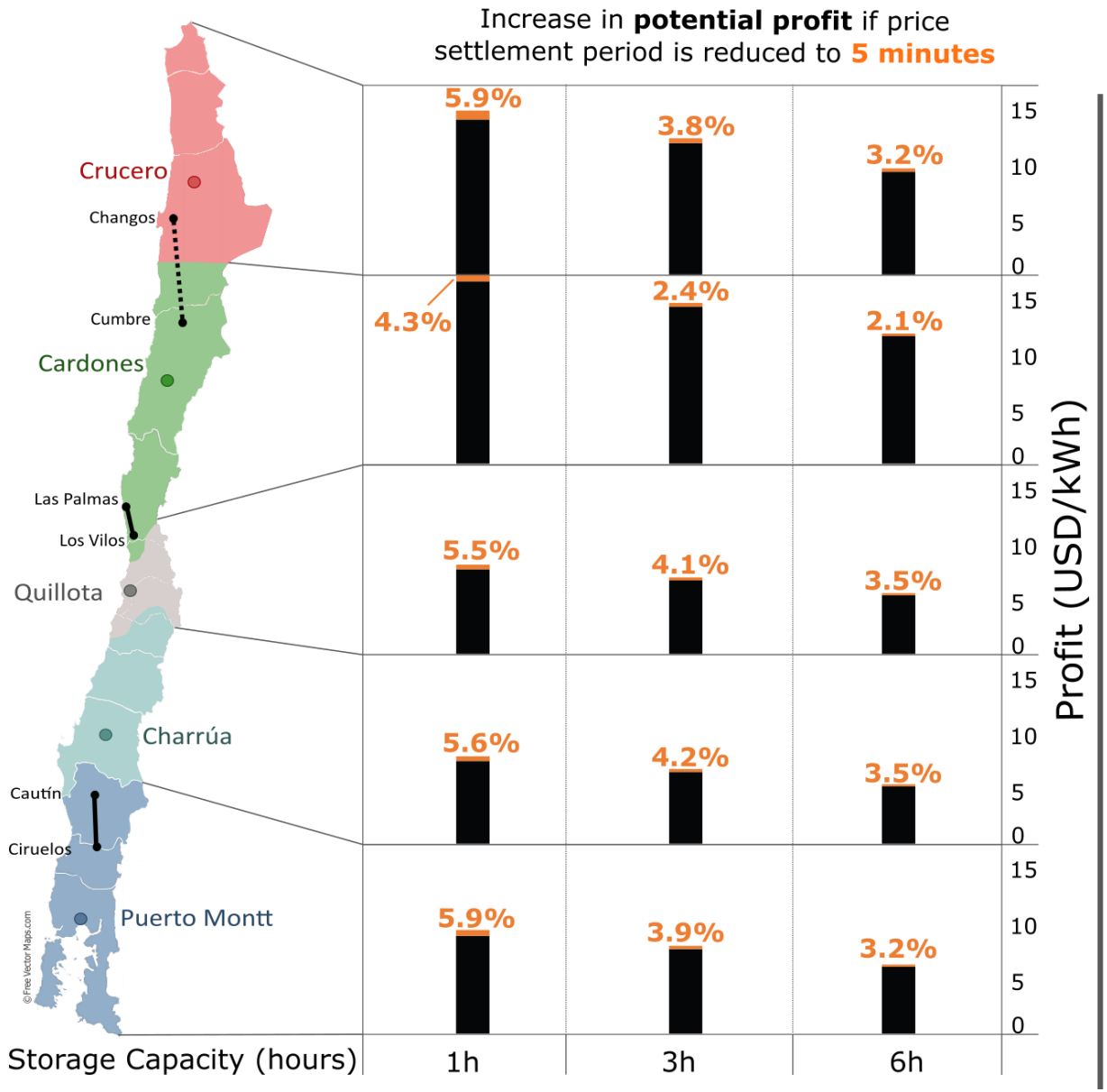
$\eta_c=\eta_d=0.95$
1 MW



The **Day-Ahead** scheduling strategies fare better than heuristics, but still miss between 30-70% of potential profit due to real-time deviations.

- Day-ahead scheduling captures higher proportion of potential profit in subsystems dominated by **solar PV production**.
  →Downside is smaller.
- Correcting the **day-ahead forecast** prices with **actual prices from the previous day** increases profit by an average of **5%** throughout all cases.

Results



Reducing the settlement period of spot prices from **1 hour to 5 minutes does not significantly increase potential profit for a 1h-6h BESS with 2018 prices**.

Real-time price variability in 2018 was mostly observed in the hourly scale; the **solar PV** dynamic is yet **more relevant than sub-hourly phenomena**.

However, the increase of almost 6% in potential profit **could increase as:**

- More wind power is installed.
- Load profiles become more volatile.
- Capacity reserves fall due to decommissioning of coal and diesel power plants.
- Pricing mechanism is revised (e.g. to include startup costs)

Conclusions

Real-time deviations from day-ahead forecasts and programs pose significant challenges for ESS scheduling in a context of high VRE integration and rise of system constraints.

Simulations show that for a 1-6h storage BESS:

Potential profit is highest in zones with **greatest solar PV integration**. The day-night price cycle is found to be more relevant than short-term real-time price fluctuations for a BESS with >1h storage duration.

Merit List and Real-time Heuristics for injections are not able to capture a significant proportion of potential profit, given that optimal buy and sell periods are often separated by several hours. These strategies also cause **greater cycling and, thus, wear**.

Day-ahead scheduling strategies can capture higher proportion of potential profit. Proportion and absolute value are **increased for higher storage durations**.
Including **day-before information in the scheduling process can increase captured profit**.

Reducing the price settlement period from 1-hour to 5-minute intervals could increase potential profit up to 6% in some cases. This opportunity is expected to increase over time.

Recommendations

Proposed Rule for Coordination and Operation of the National Electric System should be revised so that participation models of ESS allows them to produce and capture more value in the Wholesale Energy Market.

In particular, regulation should provide more **certainty to investors in ESS** so that its potential to provide valuable services in a high solar PV integration context is fulfilled.

- Scheduling and dispatching procedures should be defined when an ESS project is being **developed** and not when it is already in construction.
- Scheduling window and pricing mechanism should be defined by the **developer**, and not by the ISO.
- **Make-whole payments** should be explicitly allowed for ESS for cases in which operations determined by the ISO cause them to incur in higher costs than revenues.

The **settlement period for spot prices** should be reduced from the current 1-hour interval. Even though simulations do not find a high increase in potential profit, inter-hour price volatility is expected to increase due to several market trends.

Closely follow the regulatory discussions around FERC Order 841, in particular regarding the issue of how to maintain the **ISO's independence** when it is given the ability to dispatch ESS.

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Annex 1 - Regulatory discussions relevant to ESS under way in Chile

Ancillary Services

ESS will be able to participate in the AASS auctions that will begin on January 1st, 2020. Committed AASS take priority over energy arbitrage services.

Capacity

Regulatory discussions are under way with the objective of defining the participation model of ESS in the capacity market.

Transmission

The Draft Rule for Transmission Systems under revision is expected to explicitly deal with the *double income* issue for ESS that are included in the Tx Expansion Plan, which receive regulated payments. Additionally, the Rule should define the methodology through which ESS alternatives will be evaluated.

Wholesale Energy Market

The Rule for Operation of the Spot Market under revision is expected to be amended so that a **more adequate participation model** is applied to ESS.