system design & management

Renewable Energy Integration Opportunities & Challenges in Chile

MITsdm

Jorge Moreno SDM 2011
Donny Holaschutz SDM 2010

Agenda

- Trends in Wind & Solar Integration in Chile
- Emerging Dynamics in the Power System
  - Changes in the Net Load
  - Regionalization of Power System Dynamics
  - New Modes of Operations of Existing Units
  - Emerging Socio-Technical Constraints
  - Real Time Deviations from the Day Ahead Plan
  - Challenges to Operations of Reserves
  - The Interactions between Carbon Policy & the Power Market
- Opportunities to Utilize Existing Flexibility & Encourage Investment in New Flexibility

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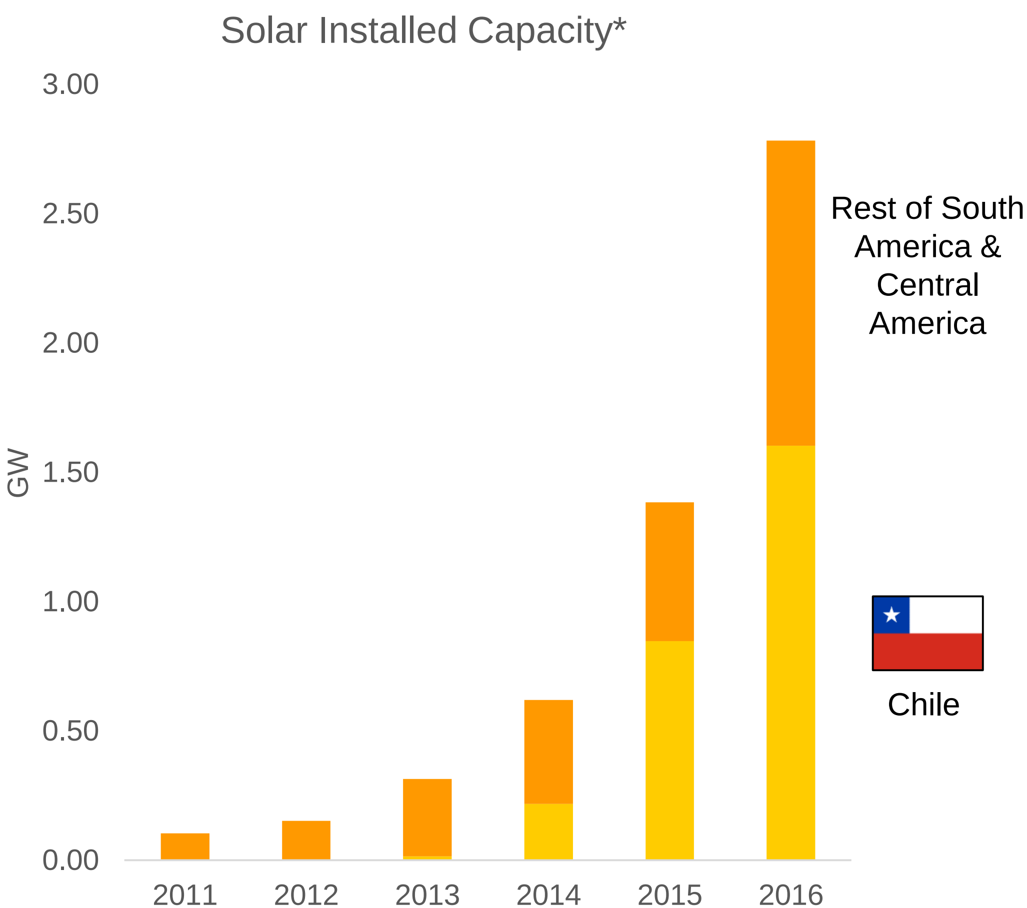
Chile has been a Leader in Integration of Renewable Energy



Country	% Percentage of Solar & Wind Generated (2016)*
Denmark	44.6%
Lithuania	27.3%
Spain	22.8%
Portugal	22.0%
Ireland	20.2%
Germany	17.8%
Greece	17.1%
Italy	14.2%
United Kingdom	14.1%
Romania	13.2%
Belgium	9.9%
Sweden	9.9%
Austria	9.2%
Netherlands	8.3%
Australia	7.9%
Poland	7.6%
US	6.6%
Turkey	6.3%
Chile	**6.3%**

*BP Statistical Review of World Energy

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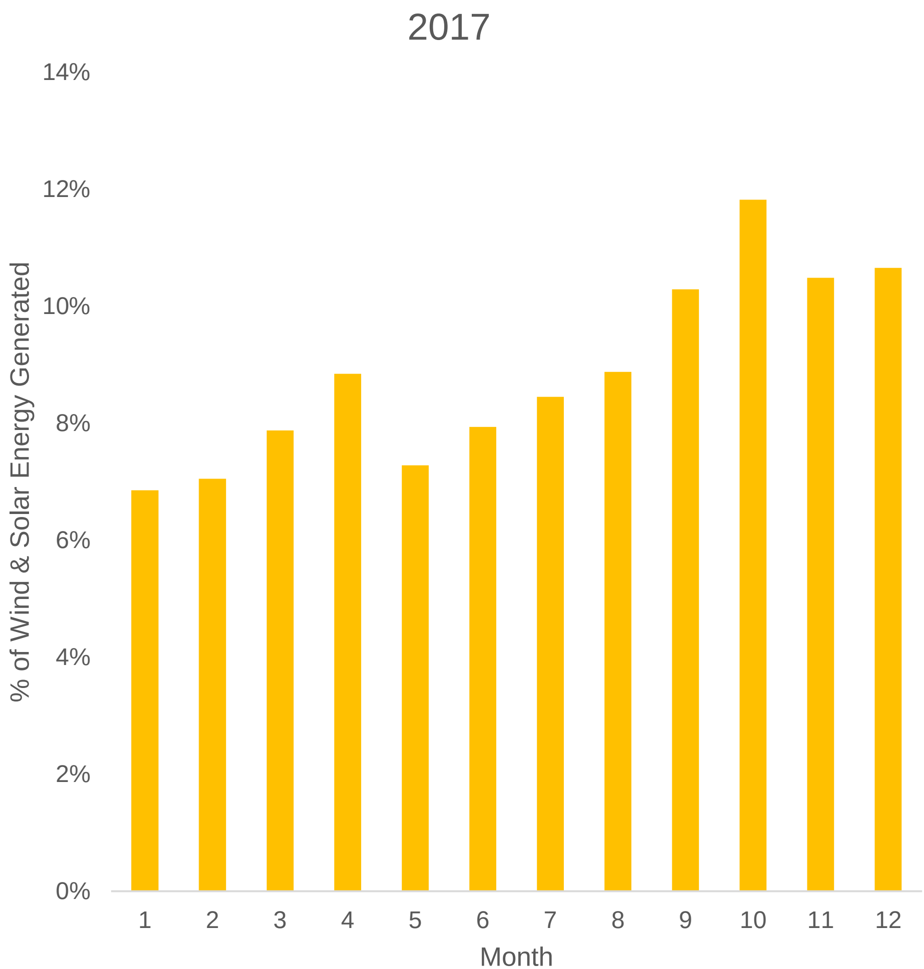

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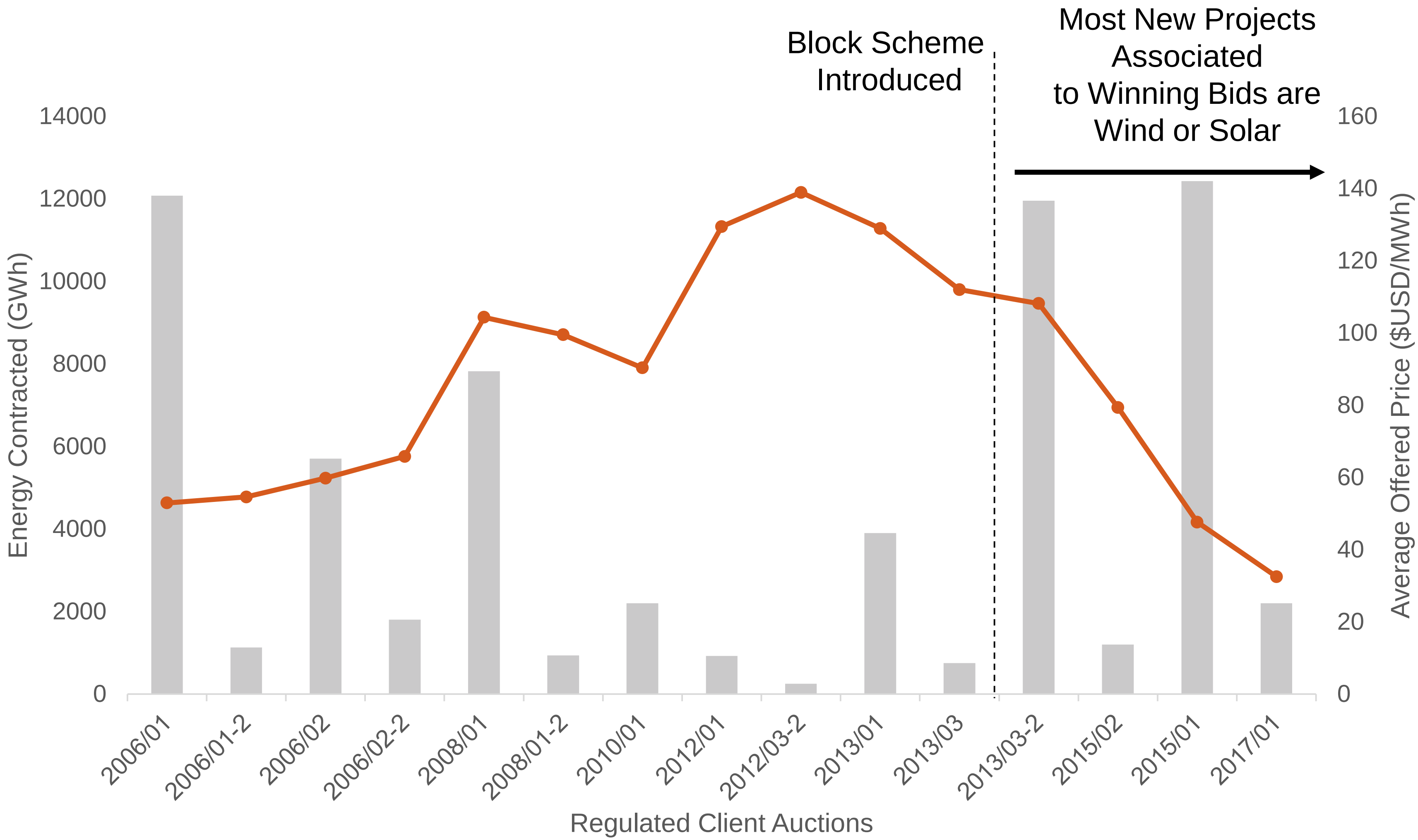
Sweden	9.9%
Austria	9.2%
Netherlands	8.3%
Australia	7.9%
Poland	7.6%
US	6.6%
Turkey	6.3%
Chile	6.3%

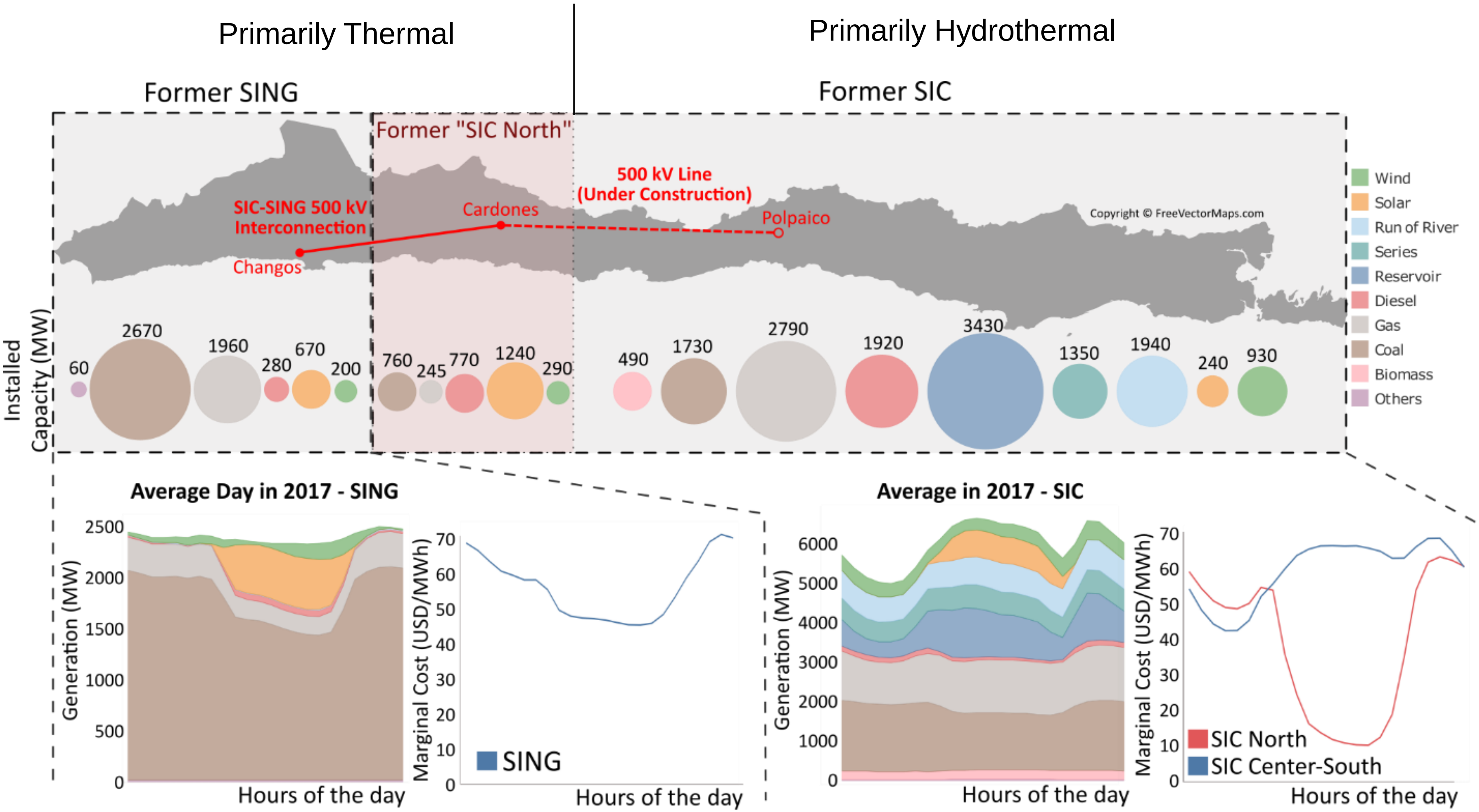
Chile Exceded 10% in 2017

*BP Statistical Review of World Energy

High Energy Prices & Opportunities to Sign PPAs have Driven Integration



Overview on the Chilean National Electricity System: Current Regional Dynamics



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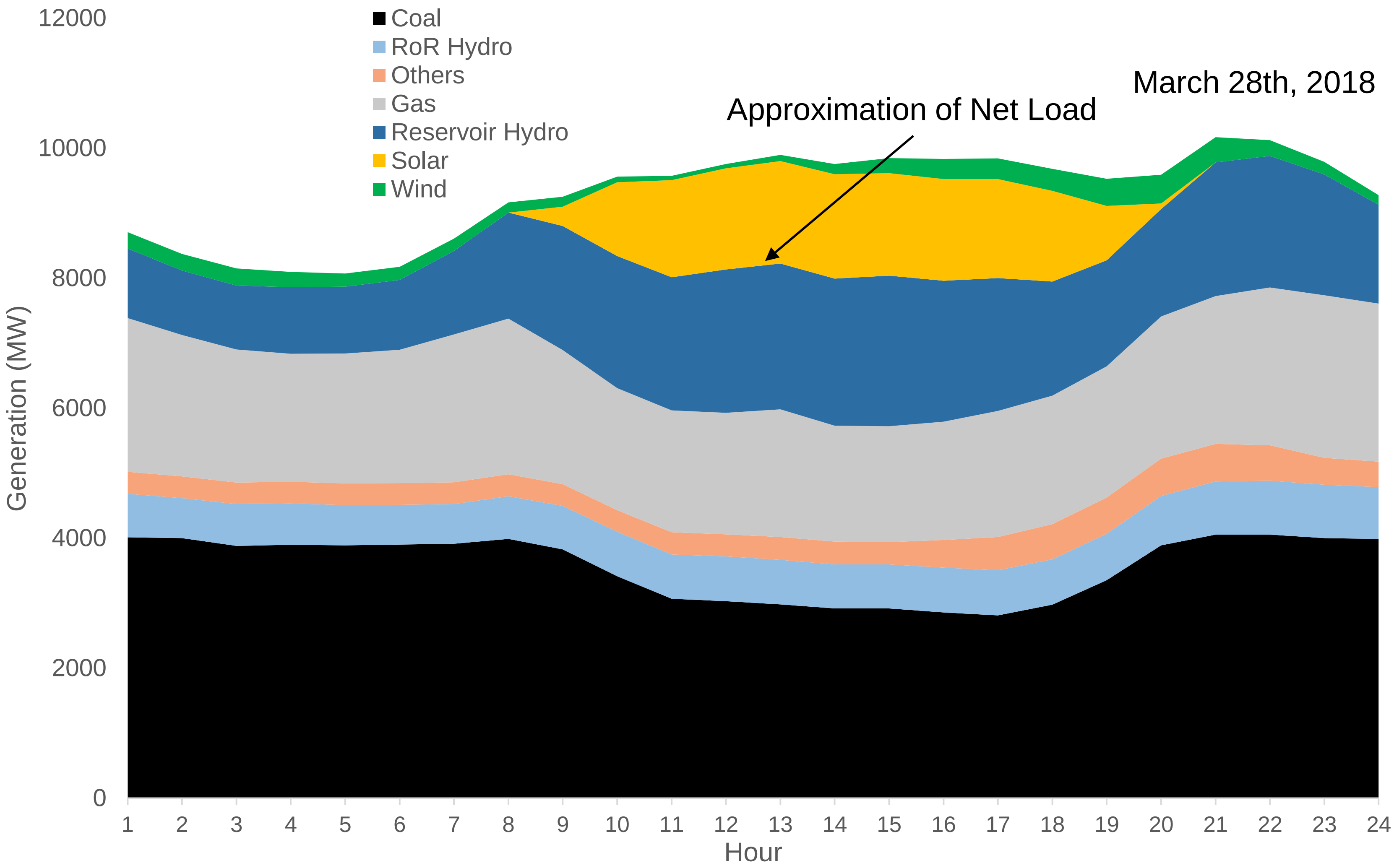
Wind and Solar Integration is Changing the Net Load



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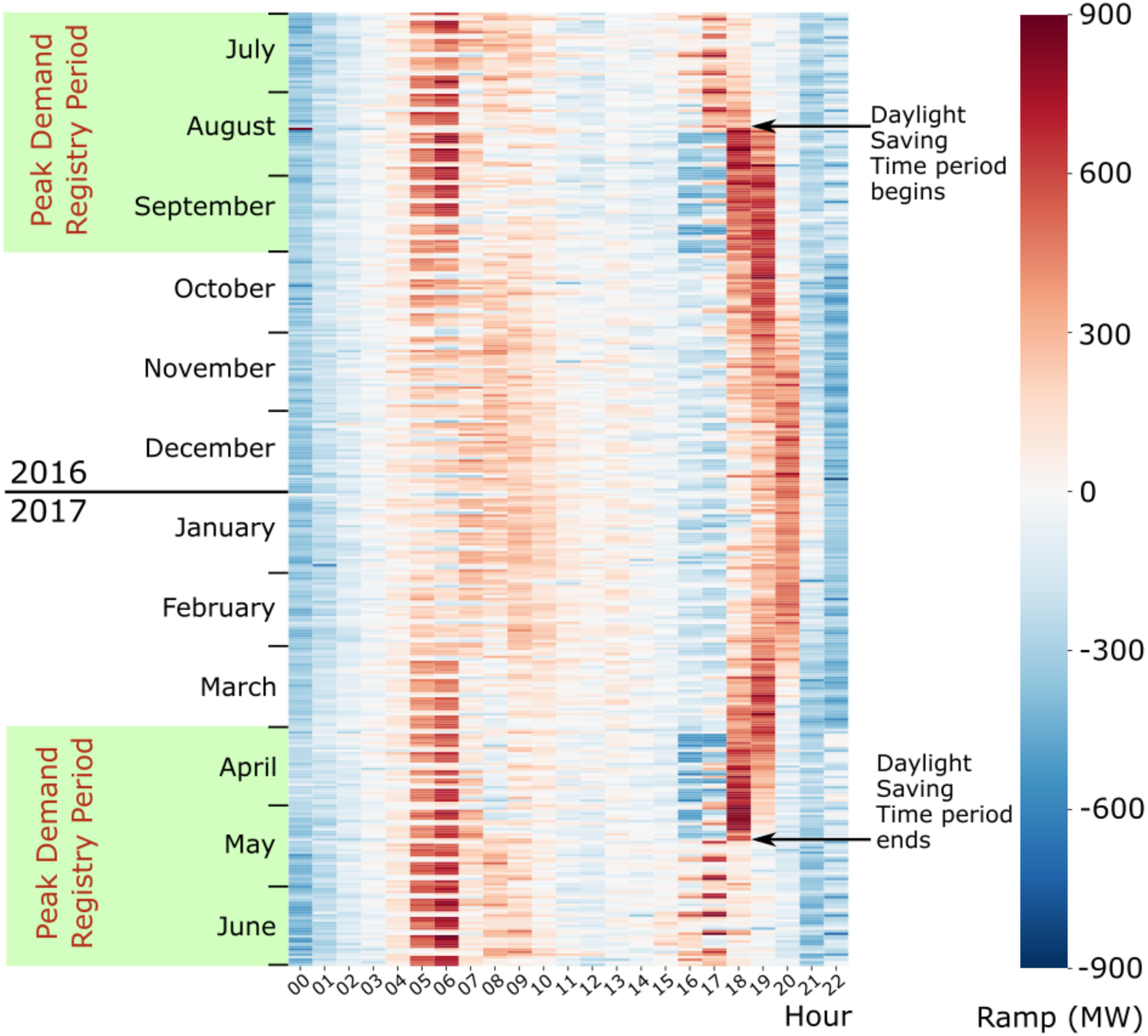
One-Hour Net Load Ramps Requirements in the System



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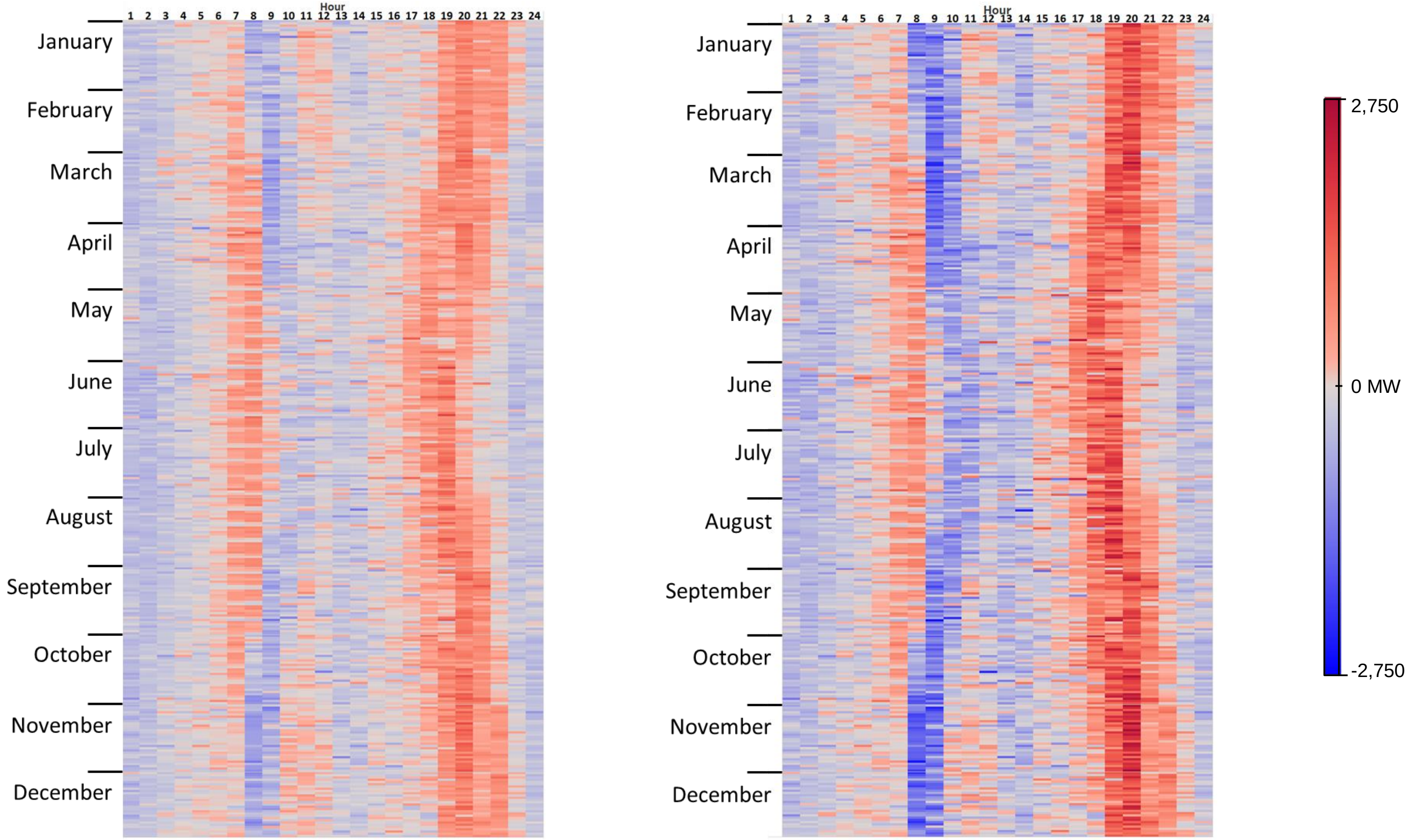
The One-Hour Net Load Ramp Requirement in the System could double by 2021 and triple by 2026

2021 **Max** 1745 MW/hr **Min** -1393 MW/hr

2026 **Max** 2837 MW/hr **Min** -2463 MW/hr

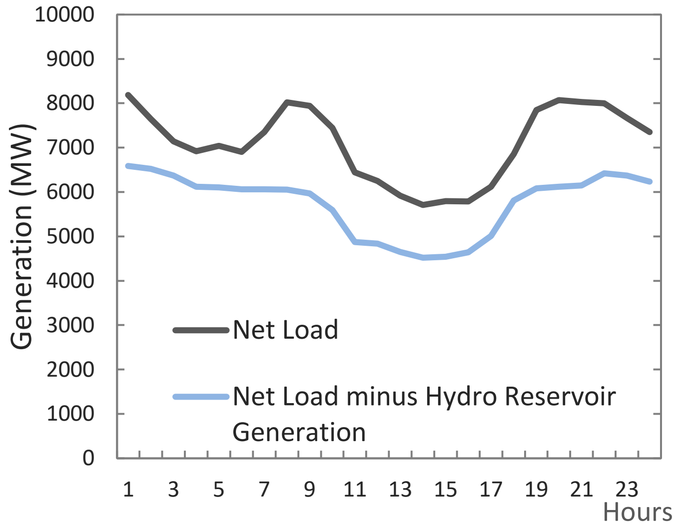


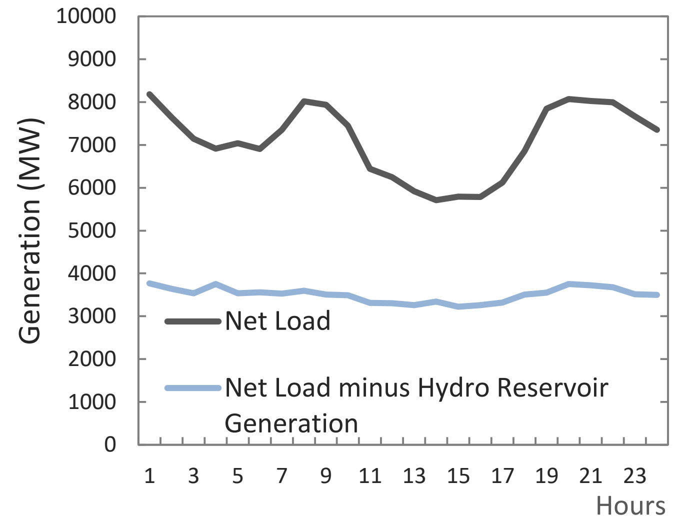
The Duck Curve does Not Always Apply to Chile

Dry Scenario (2021)

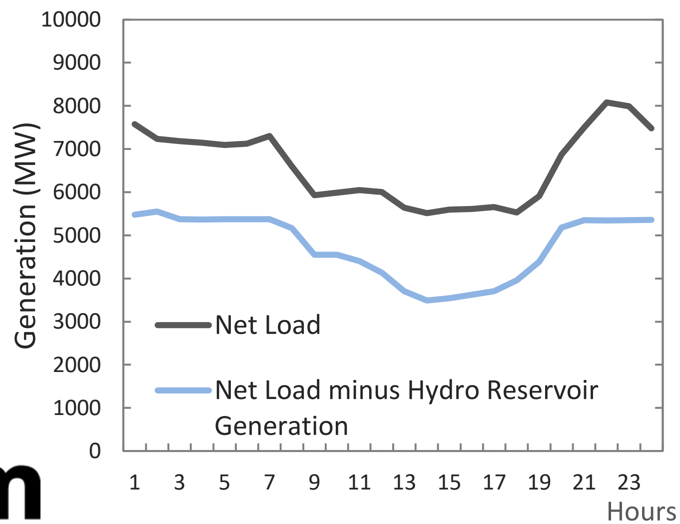
Wet Scenario (2021)

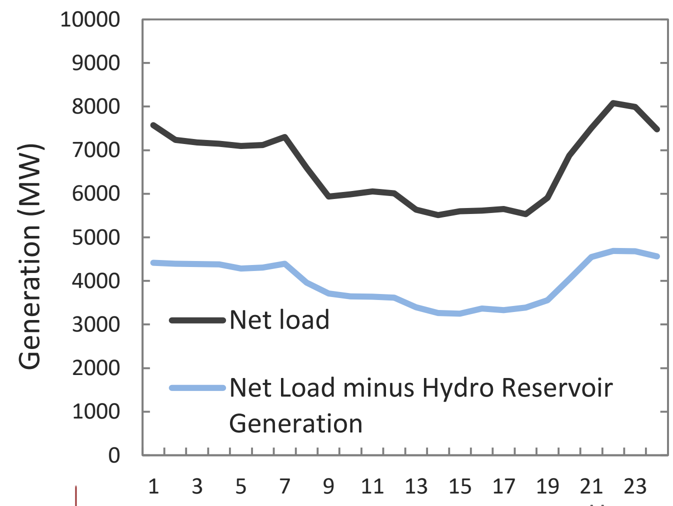
Winter Day





Summer Day



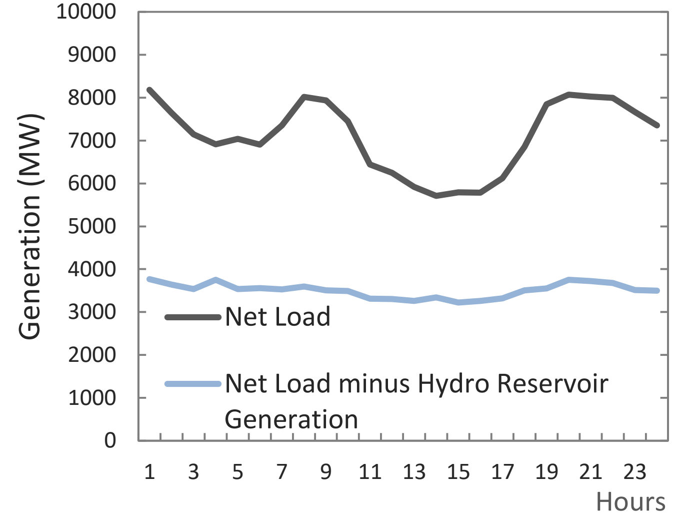


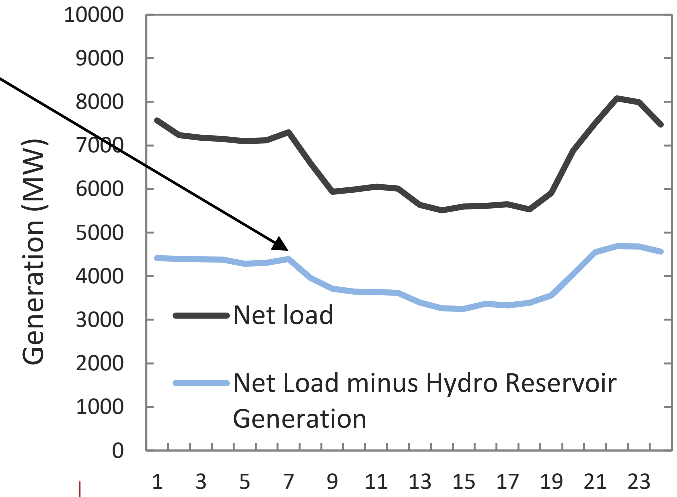
In Chile the (Net Load – Hydro Curve) Looks More like a Penguin from the Patagonia Swimming

Winter Day

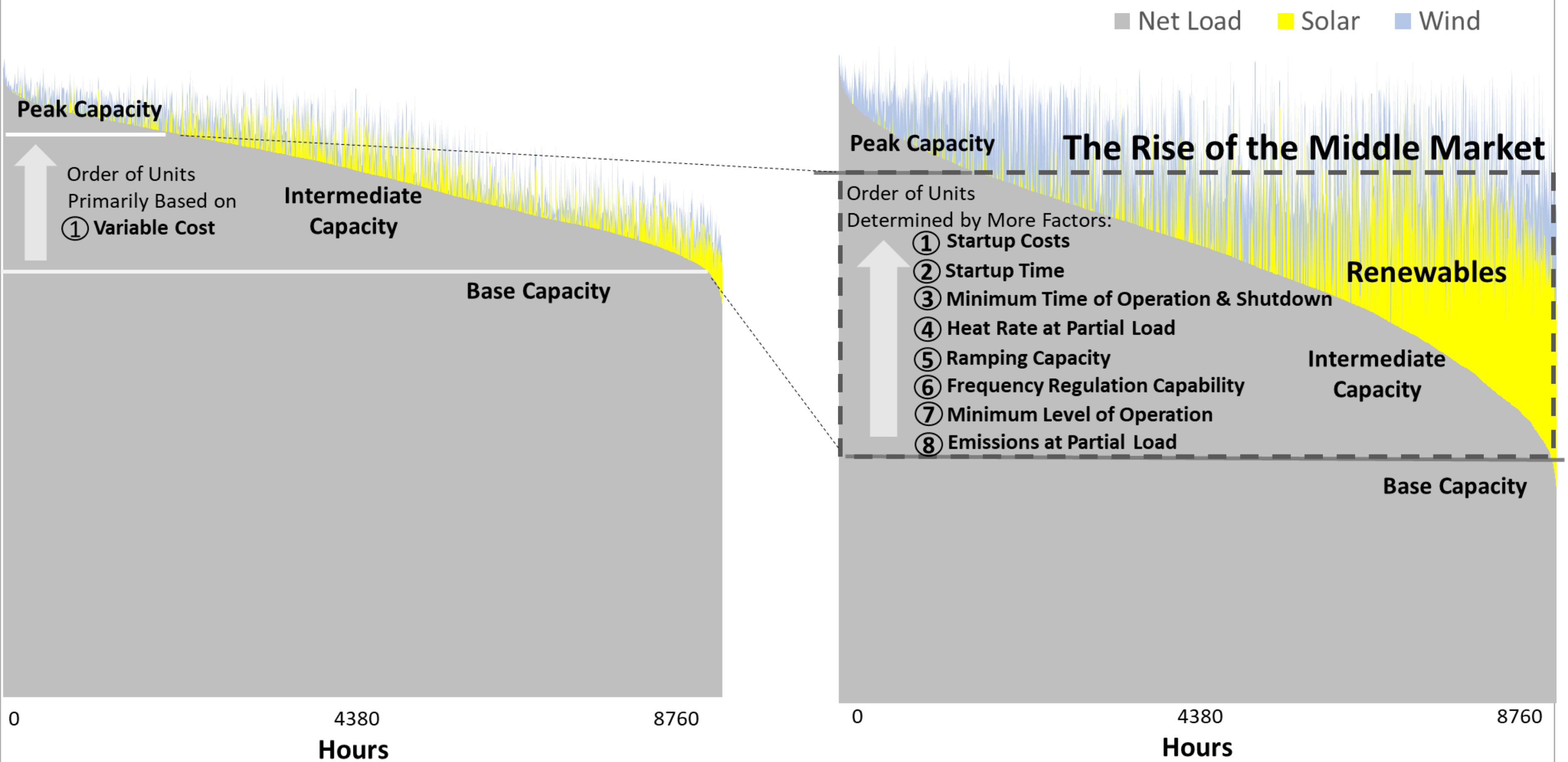
Summer Day

Wet Scenario (2021)





Integration of Solar & Wind will Give Rise to the "Middle Market"



The "Middle Market" has reached 2500 MW and could double o triple in the next ten years

Capacity Needs Are Changing with New Flexibility Needs

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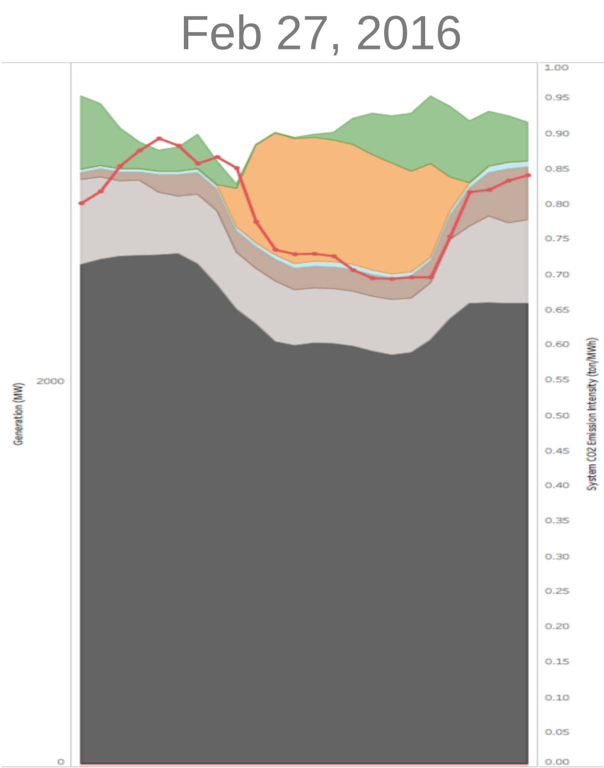
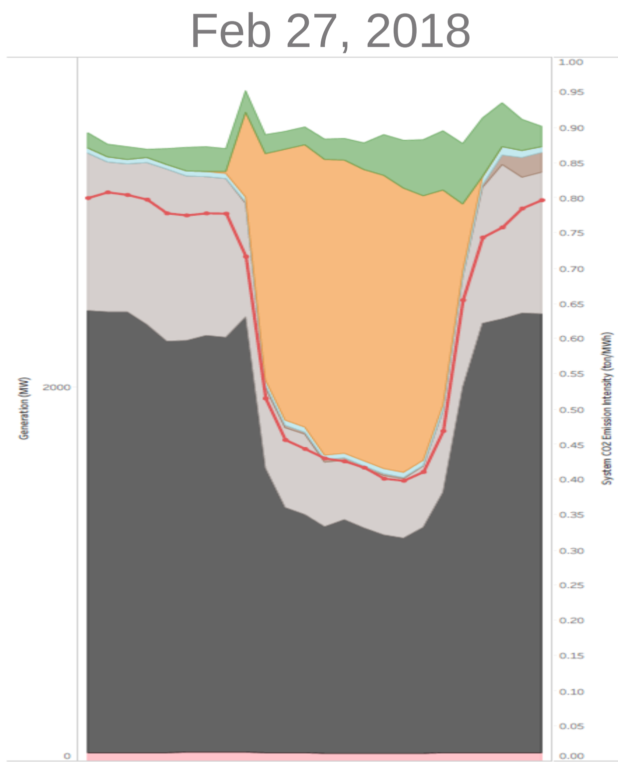
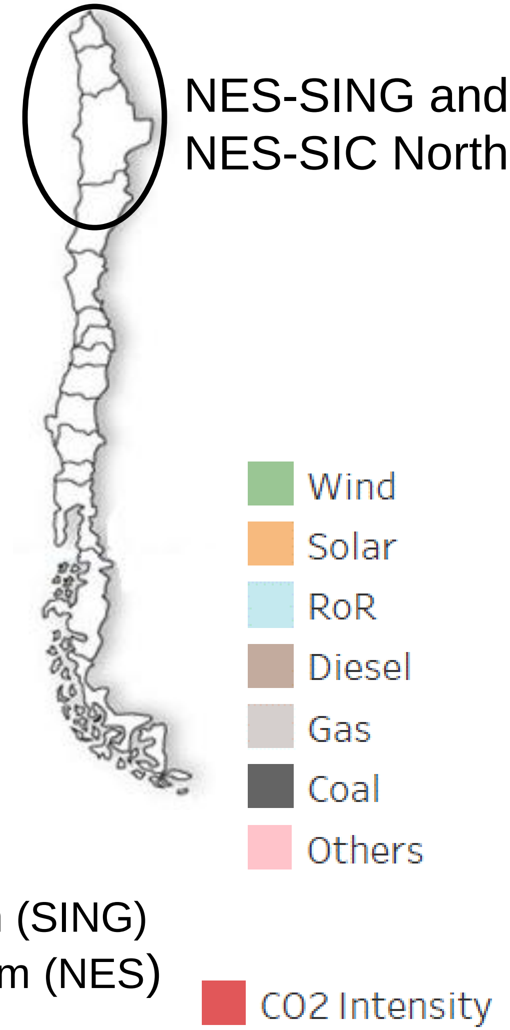
In the North – Wind and Solar Have been Integrated Rapidly





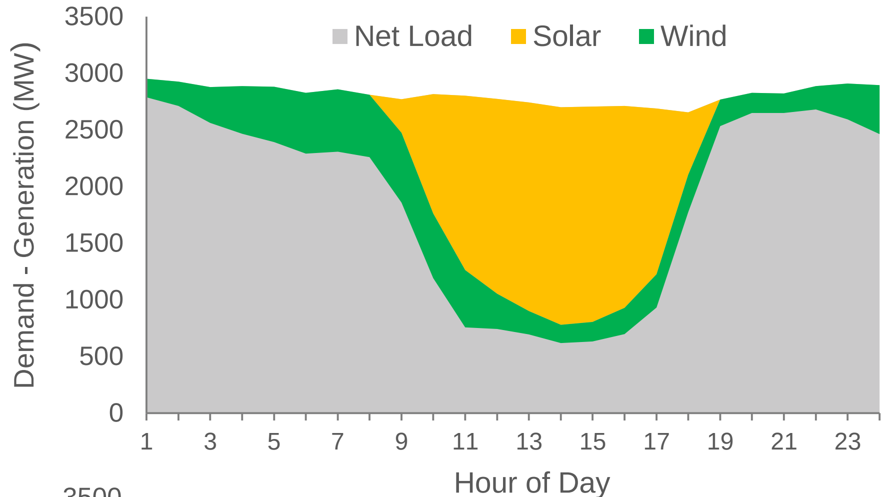


Central Interconnected System (SIC) & Northern Interconnected System (SING) were connected in November 2017 to create the National Energy System (NES)

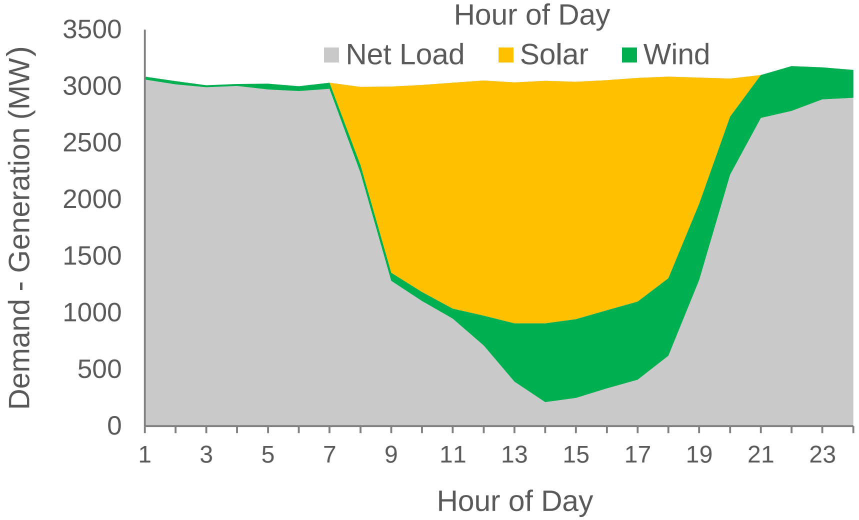
Regional Net- Load Dynamics: In the North the Duck Will Rapidly Get Chopped

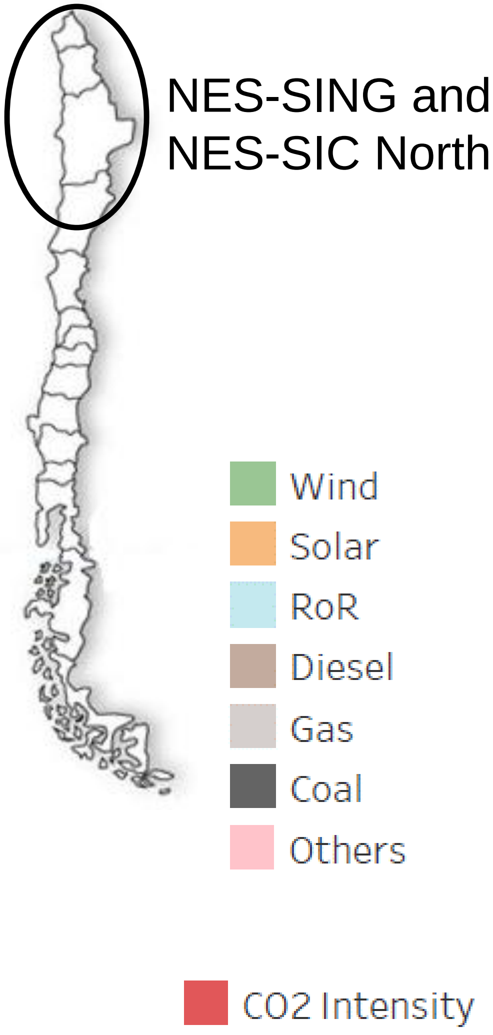
Scenario (2021)

Winter Day



Summer Day





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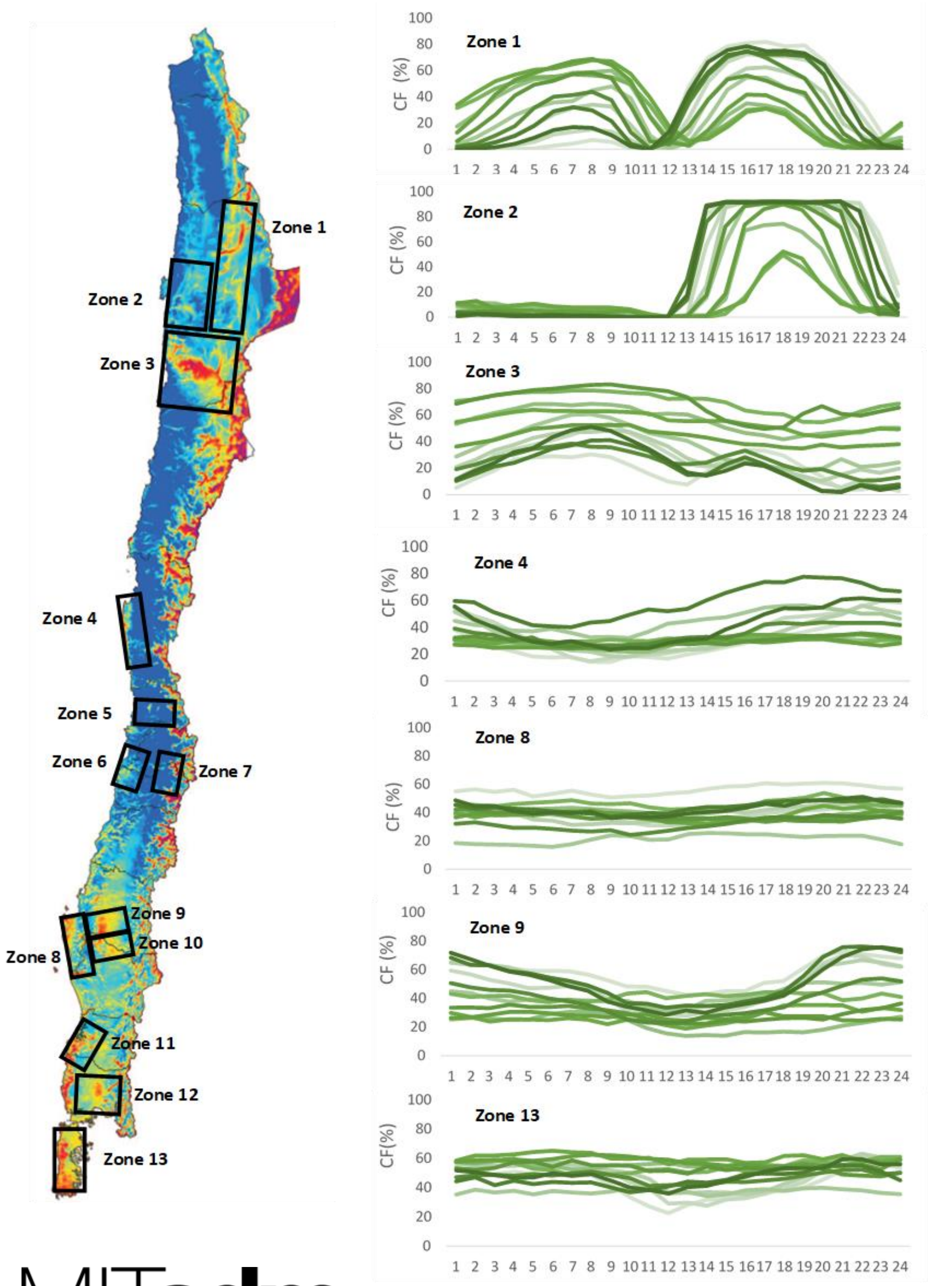

High wind generation in zone 1 & 2 coincide with the drop in solar PV production, as well as local peak demand.

As the integration of wind and solar generation increases in the north deviations from the forecasted wind generation in the north could increase the stress on the system in real-time operations.

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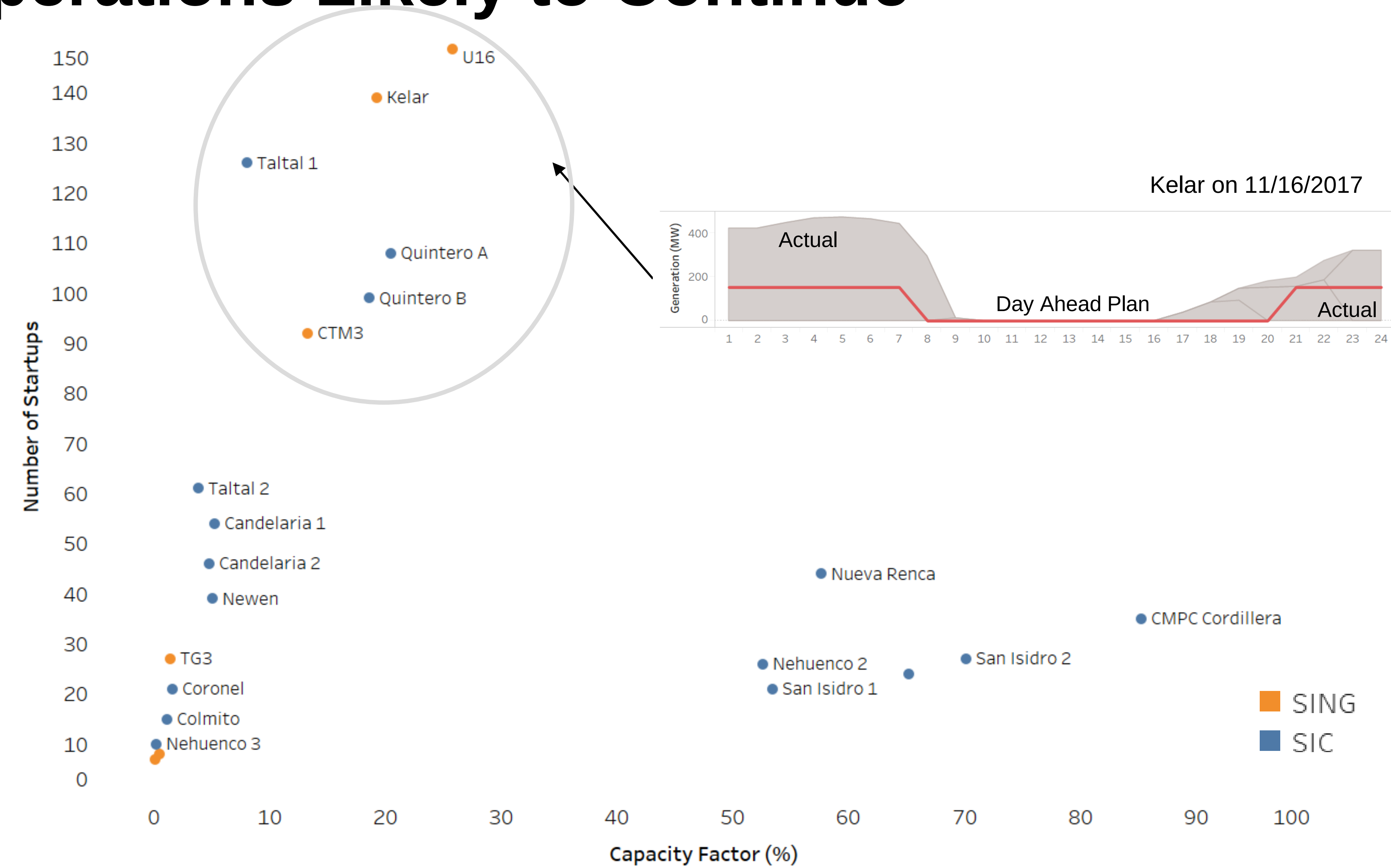
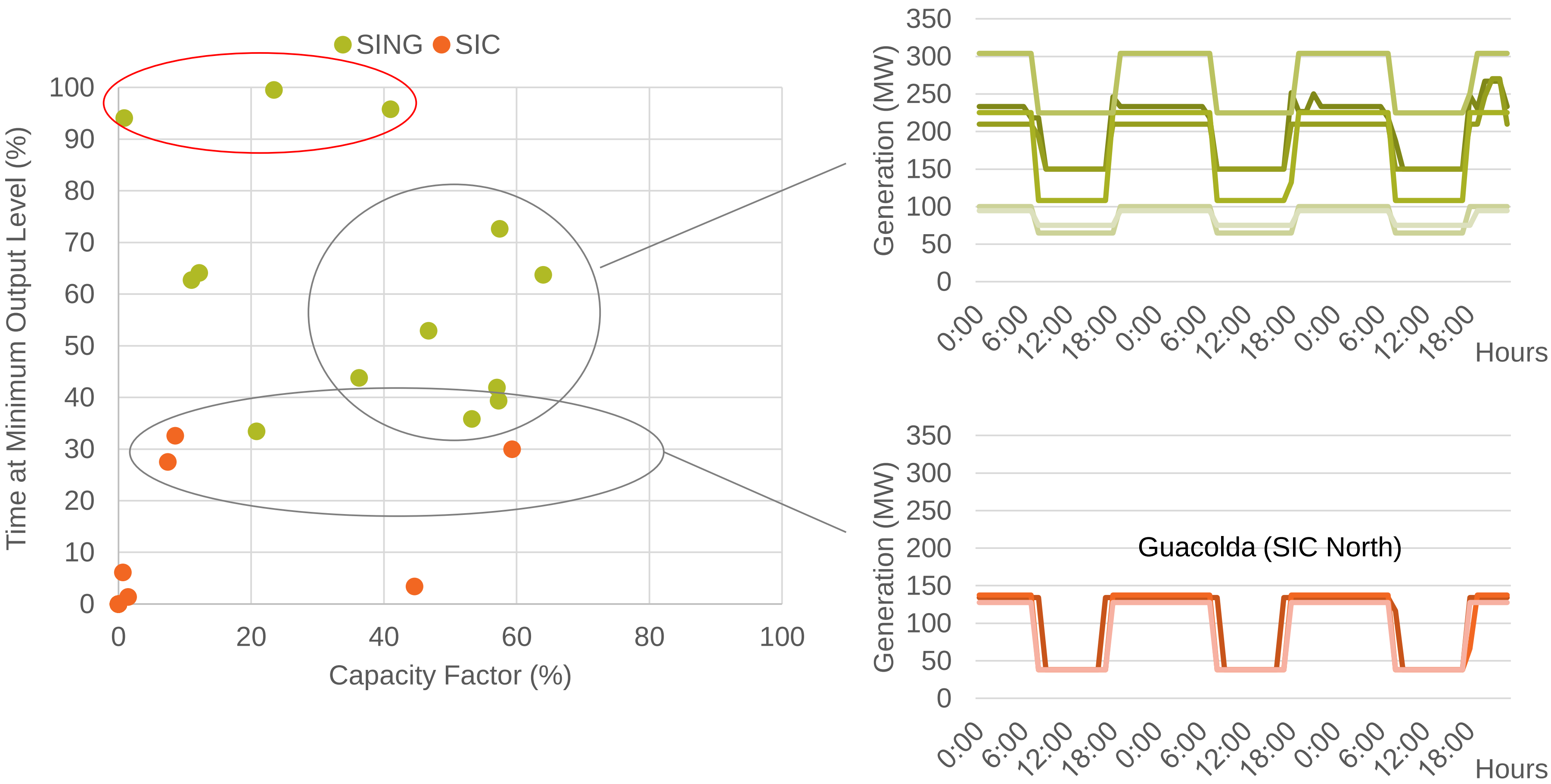
Startups Increasing in Gas Units (2017) & Operations Likely to Continue



In a 2026 Scenario with a Carbon Tax of 30 USD/ton, Coal Plants Stay on Cycling to Minimum Load



All units in the SING and the north of the SIC are kept either operating between their minimum stable level and maximum net capacity, or operating constantly at a minimum level to provide reserves.

High Variable Cost Flexible Units have been Used more than Planned (Oct 2016 - Sept 2017)

Unit	Type	Unplanned Startups	Energy Generation during Unplanned Startups (GWh)	Total Energy Generation (GWh)	% of Capacity Factor Due to Unplanned Startups
El Peñón	Diesel Engines	94	6.5	7.9	82%
Andes Generación	Diesel Engines	62	1.2	1.9	63%
Taltal 2	Gas Turbine	62	28.8	47.0	61%
Taltal 1	Gas Turbine	61	38.9	106.7	36%
Teno	Diesel Engines	56	14.3	20.5	70%
Quintero A	Gas Turbine	41	44.3	208.7	21%
Antilhue	Gas Turbine	38	12.5	42.7	29%
Newen	Gas Turbine	38	5.4	7.4	73%
Quintero B	Gas Turbine	37	37.0	189.4	20%
Trapén	Diesel Engines	37	5.6	15.6	36%
Candelaria 1	Gas Turbine	36	22.6	165.7	14%
Los Pinos	Gas Turbine	31	20.9	69.7	30%
Nueva Renca	Combined Cycle	28	103.5	2302.6	4%
Los Vientos	Gas Turbine	17	7.0	17.7	40%

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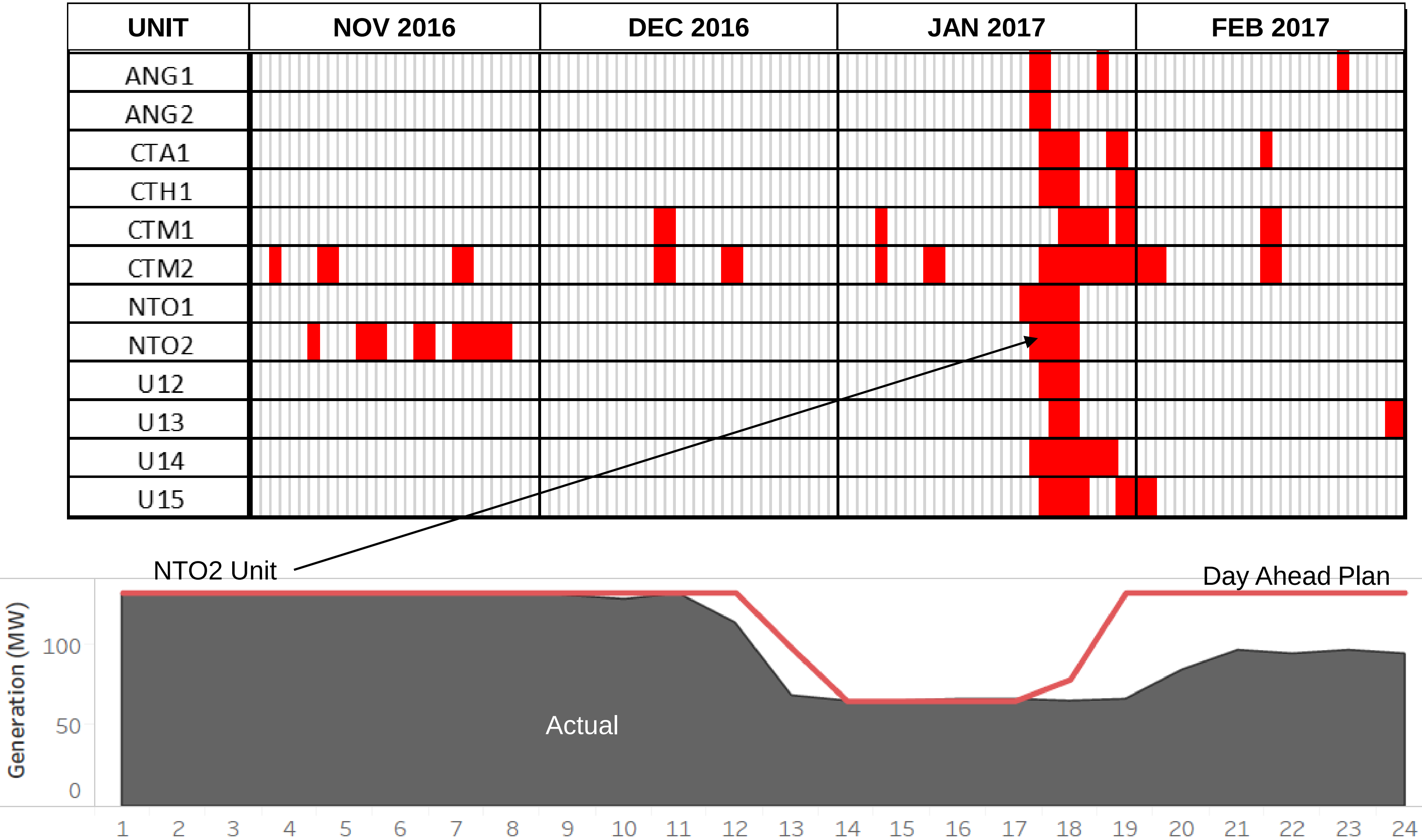
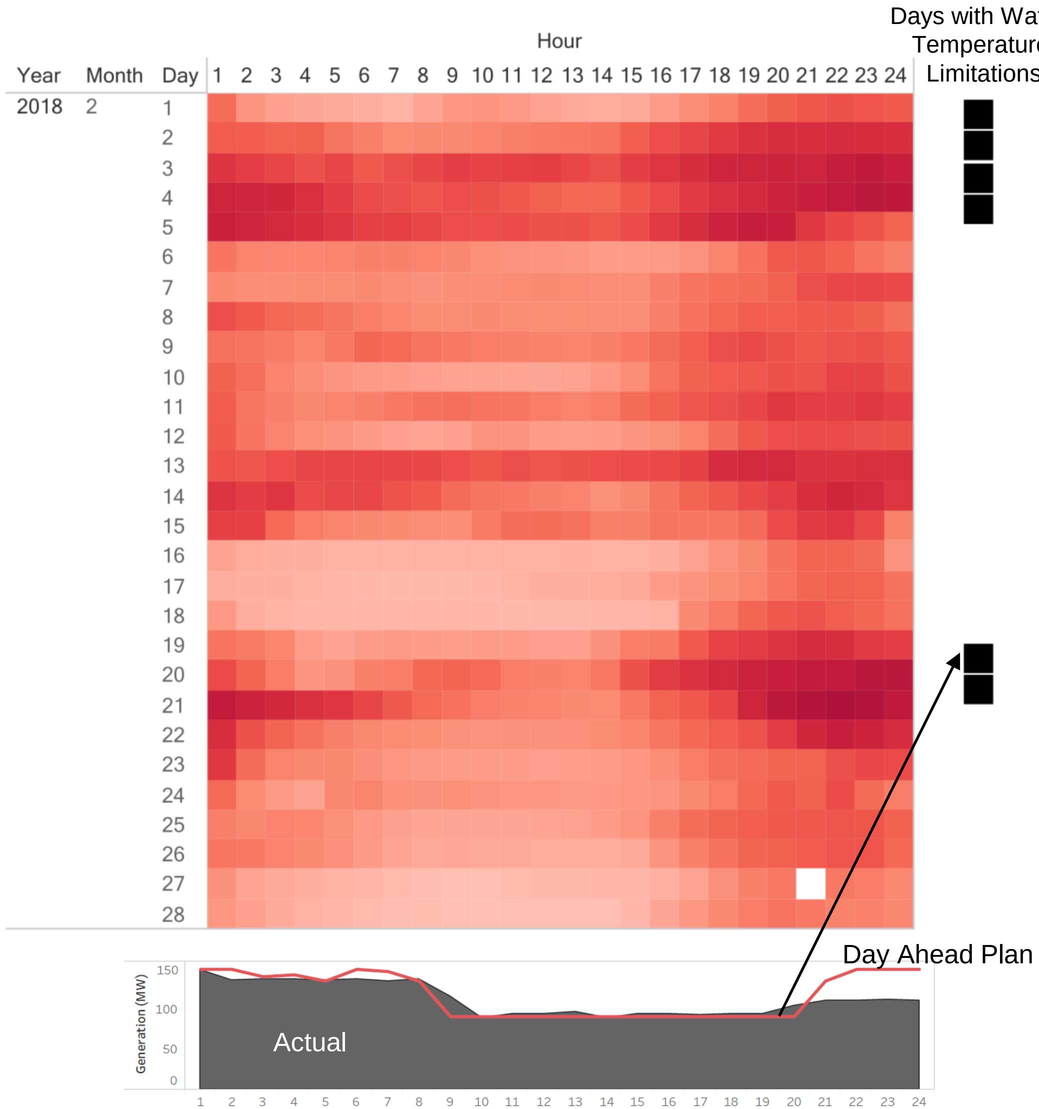
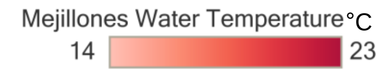
Coal Plants Affected by Effluent Temperature Limitations in the North under Strong Niño Conditions in the Pacific Ocean



Effluent Temperature Limitation of Coal Power Plants Coincides with the Drop of Solar PV Generation and Spinning Reserves





At 19:11 on Feb 20th 2018 the CTM 1 Unit Reports:

- Limitation Due to High Temperatures at the Discharge
- States that Generation Capacity will be Limited to 110 MW

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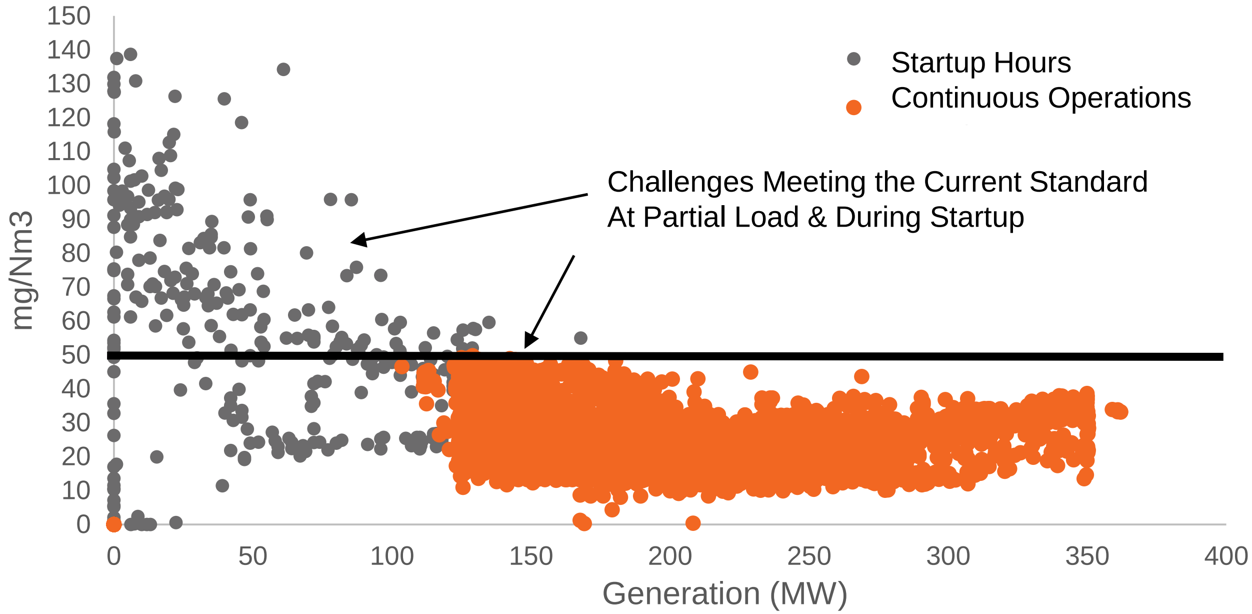
Defined Local Emissions Limits Can Affect Power Market Operations

Emissions Limits for Existing Units

Fuel	Particulate Matter (MP) mg/Nm3	Sulfur Dioxide (SO_2) mg/Nm3	Nitrous Oxide (NO_x) mg/Nm3
Coal	50	400	500
Liquid	30	30	200
Gas	N/A	N/A	50

MP & SO2 can exceed the limit 5% of the hours due to (startup, shutdown, and trips)
NOx must meet limit during 70% of the hours operating, including startup periods.

NOx Emissions Measurement of a Gas Unit (CCGT)



In 2016 gas units exceeded:

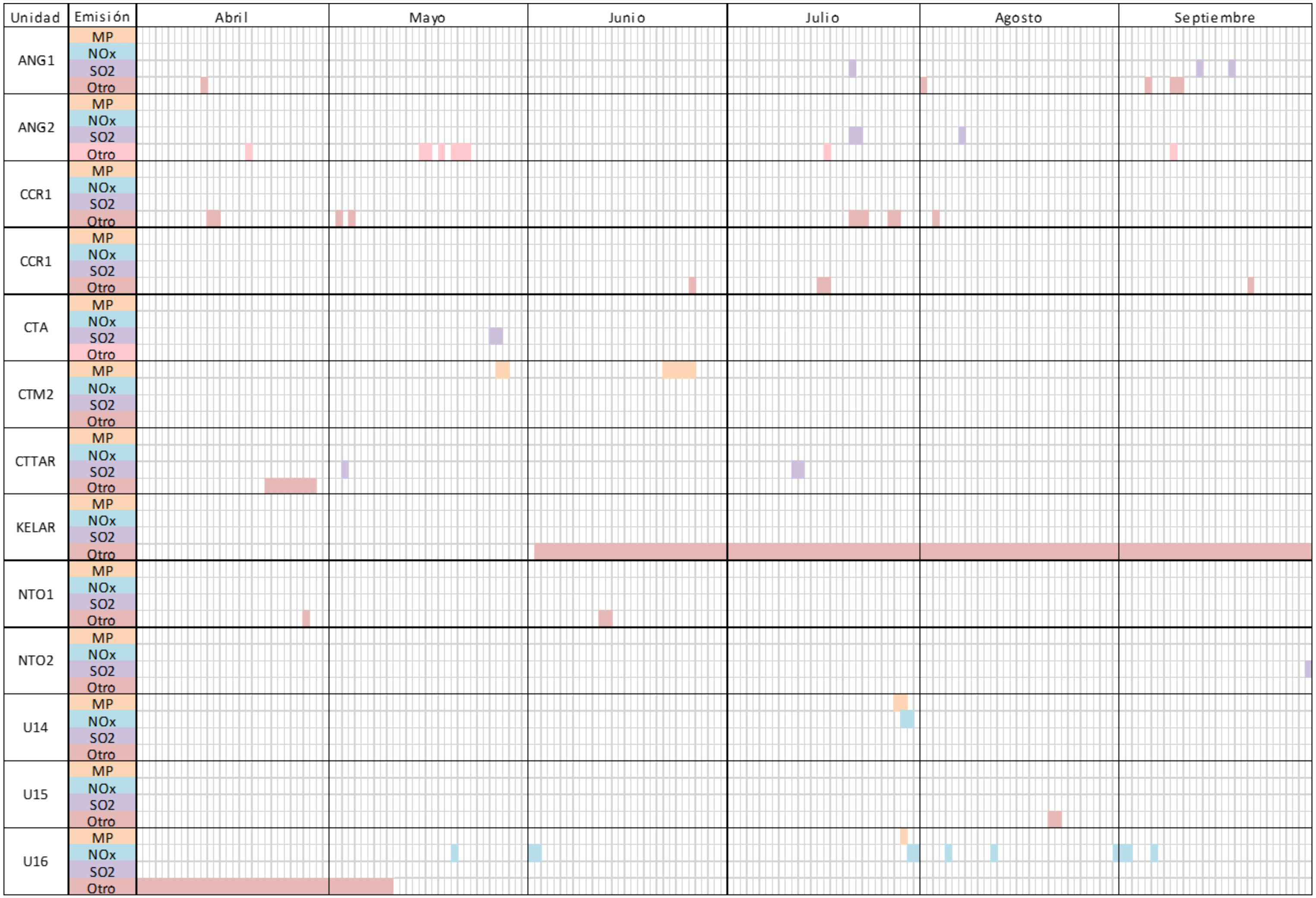
- NOx limits for existing units 54% of the time during startup

In 2016 coal units exceeded:

- PM & SO2 limits for existing units 23% of the time during startup
- NOx for existing units 12% of the time during startup

*Ministry of Energy 2017

Limitations can Affect Power Market Operations



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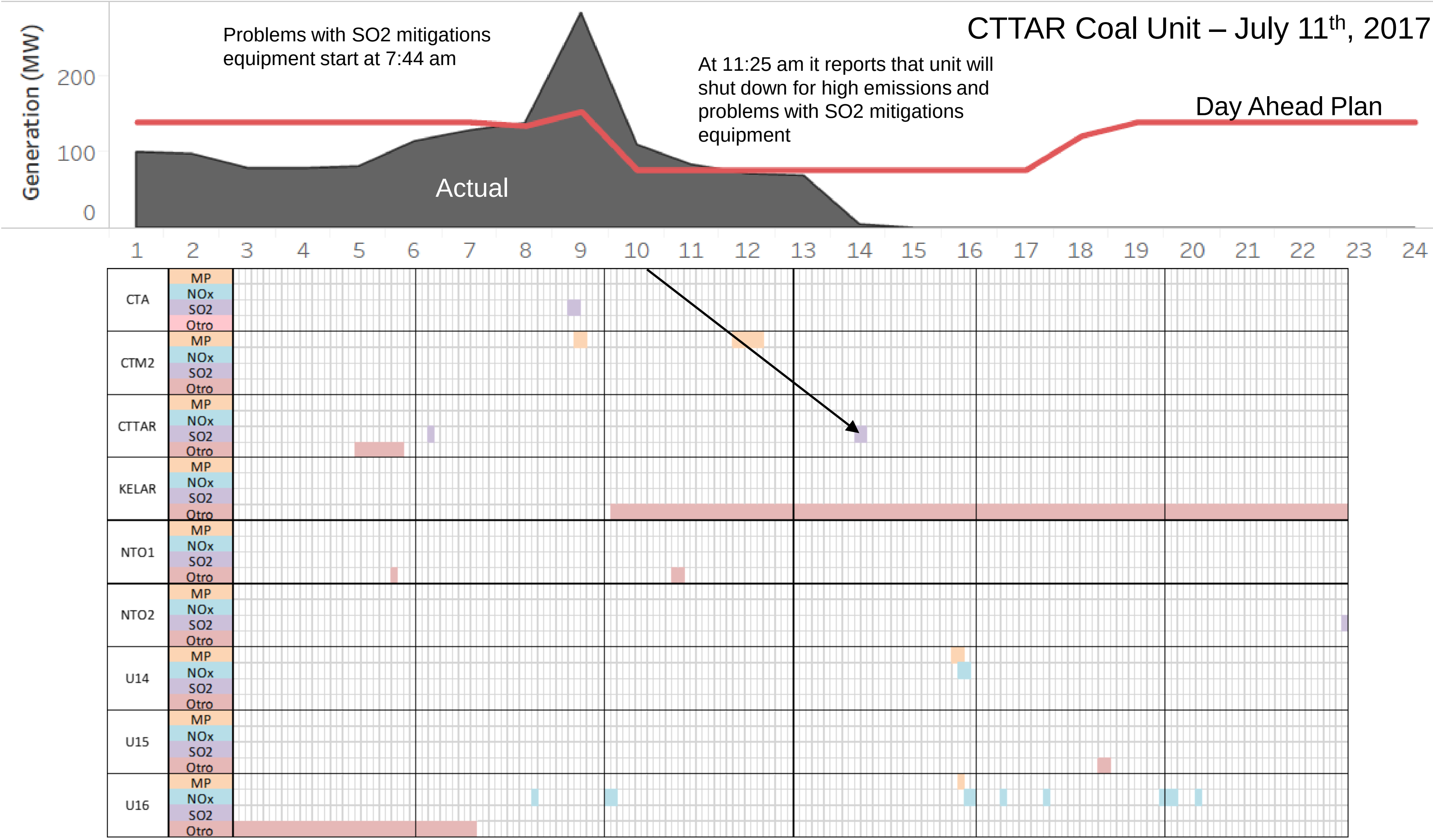

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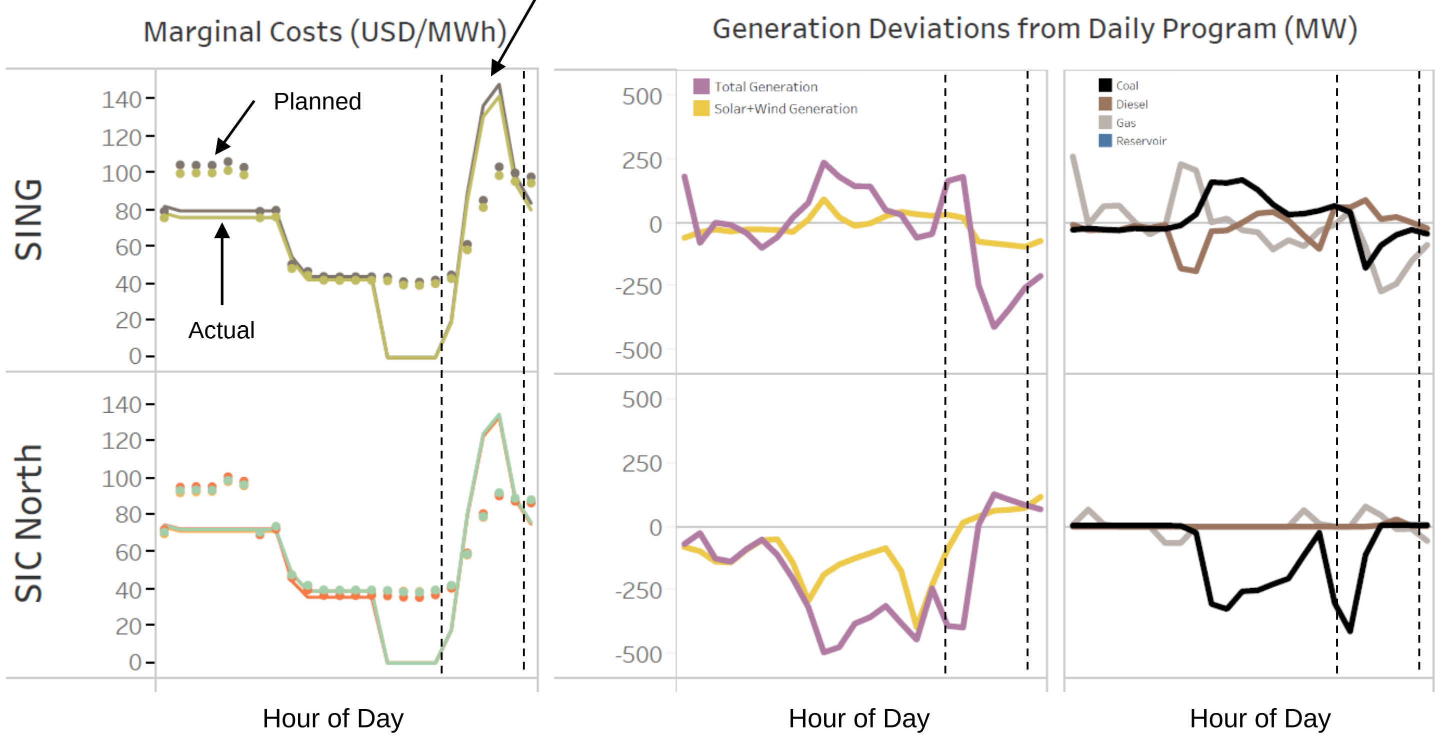
Dynamics of 3-13-2018 in the North part of the SEN

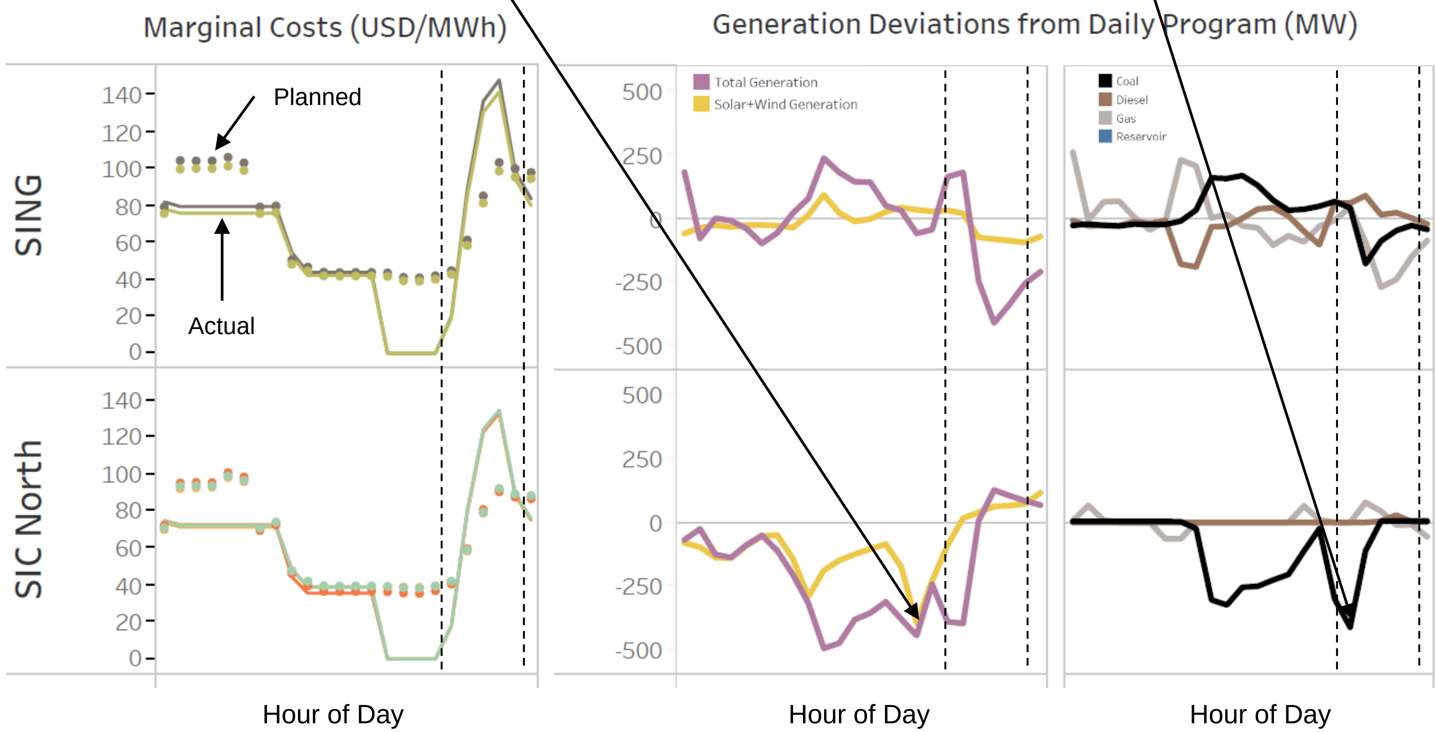
Marginal Costs Reached
148 $USD/MWh at 10pm



Dynamics of 3-13-2018 in the North part of the SEN

Wind and solar generation
398 MW less than expected at 3pm

Coal generation rapidly deviating reaches 414 MW less than expected at 7pm



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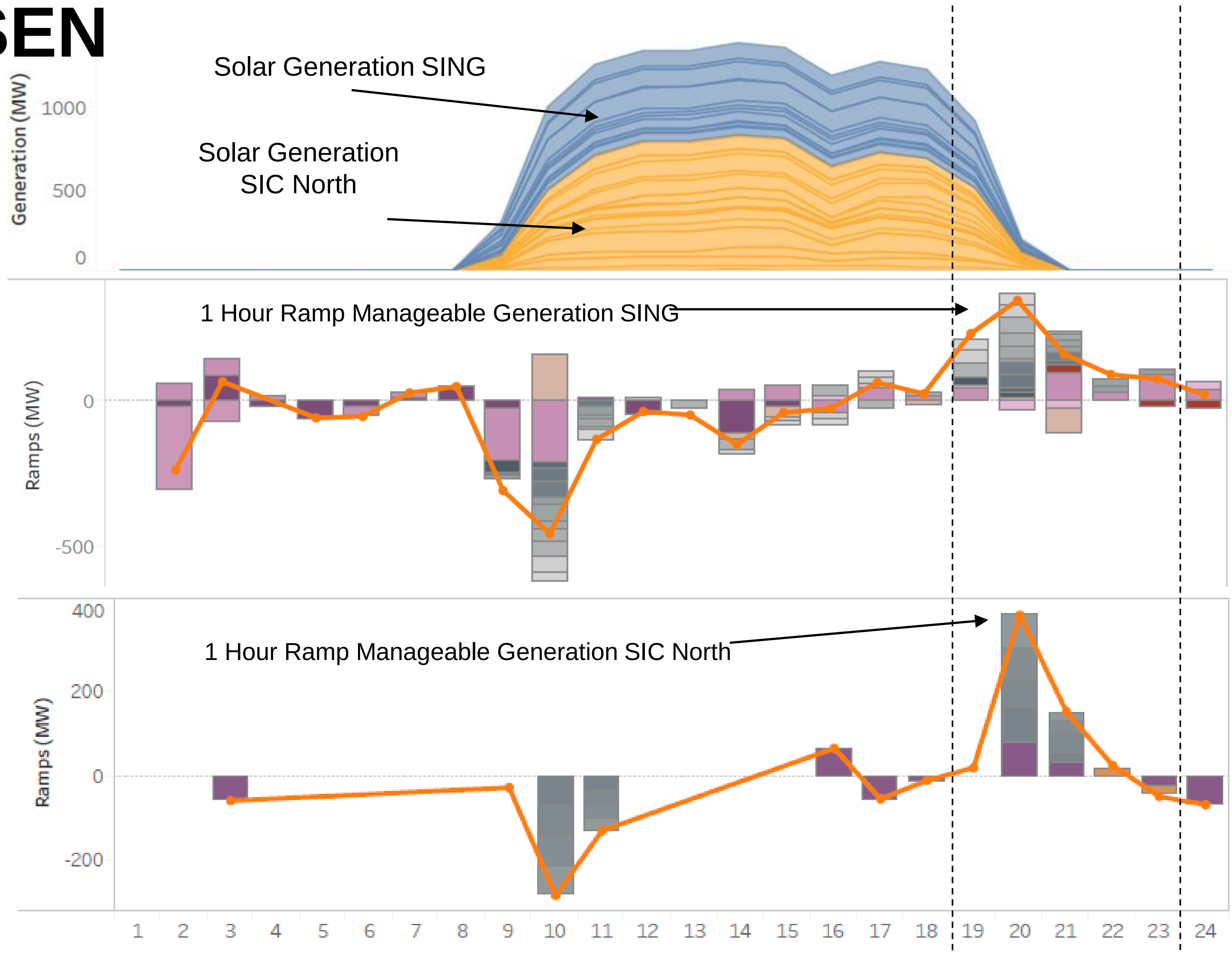
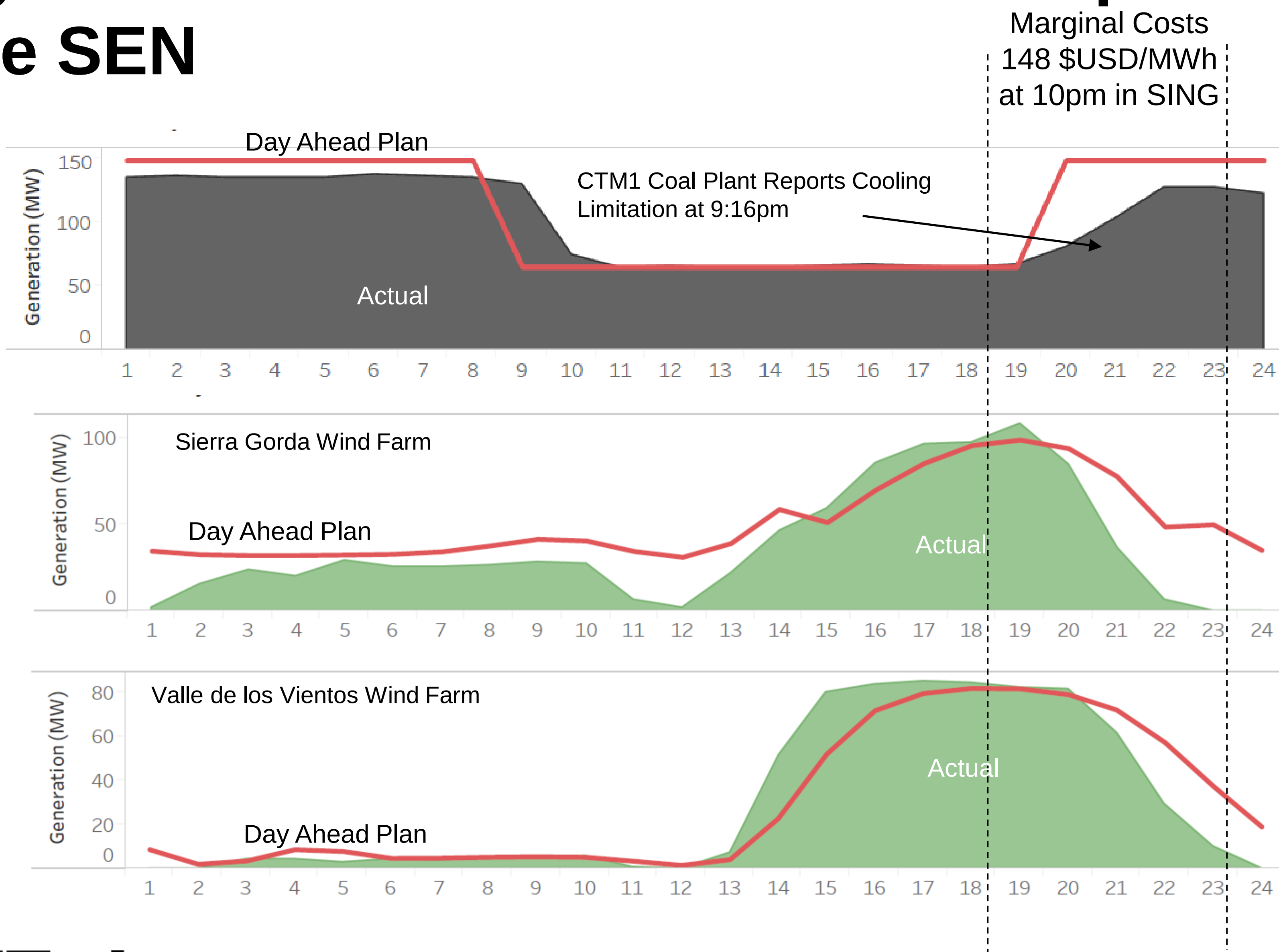
Dynamics of 3-13-2018 in the North part of the SEN

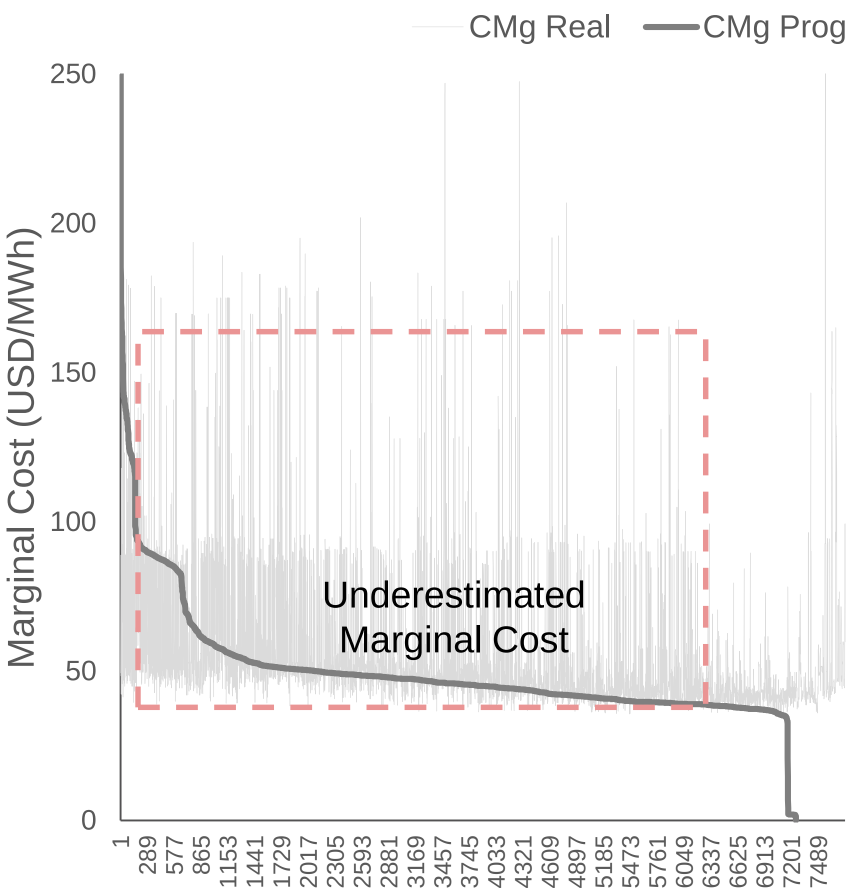


Dynamics of 3-13-2018 in the North part of the SEN

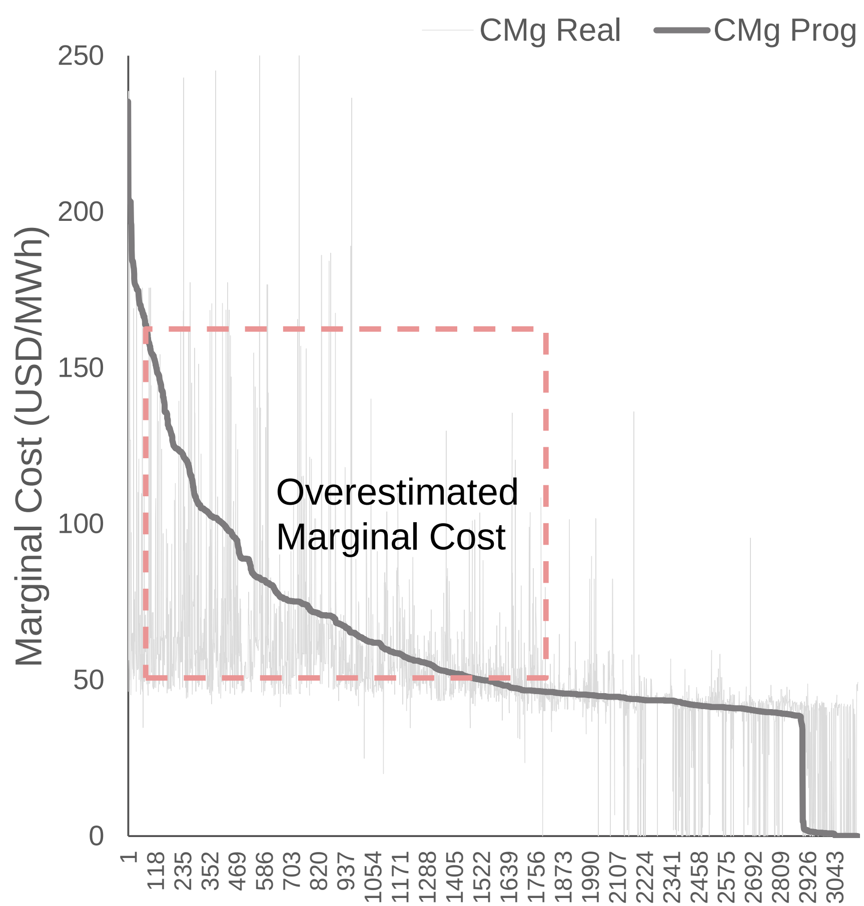


Variations between the Planned Marginal Costs (Day Ahead) and the Real in the SING

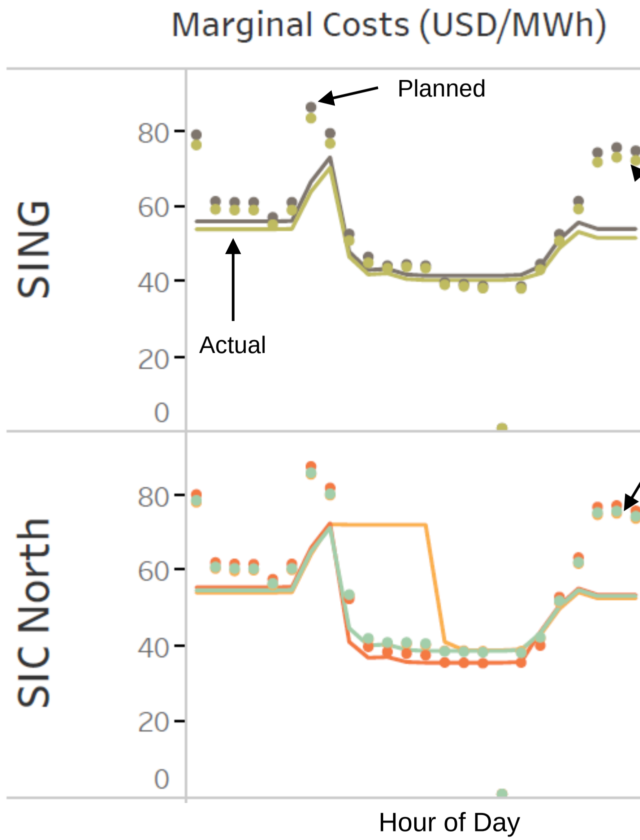
Marginal Cost SING (Crucero Busbar)
Pre-Interconnection (Jan 2017 – Nov 2017)



Marginal Cost SING (Crucero Busbar)
Post-Interconnection (Nov 2017-Mar 2018)



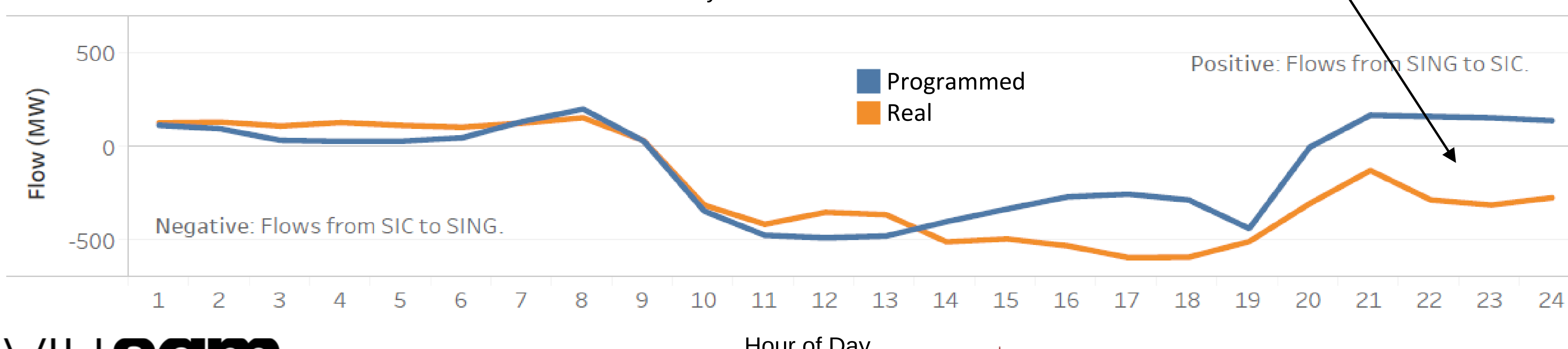
Dynamics of 3-26-2018 in the North part of the SEN



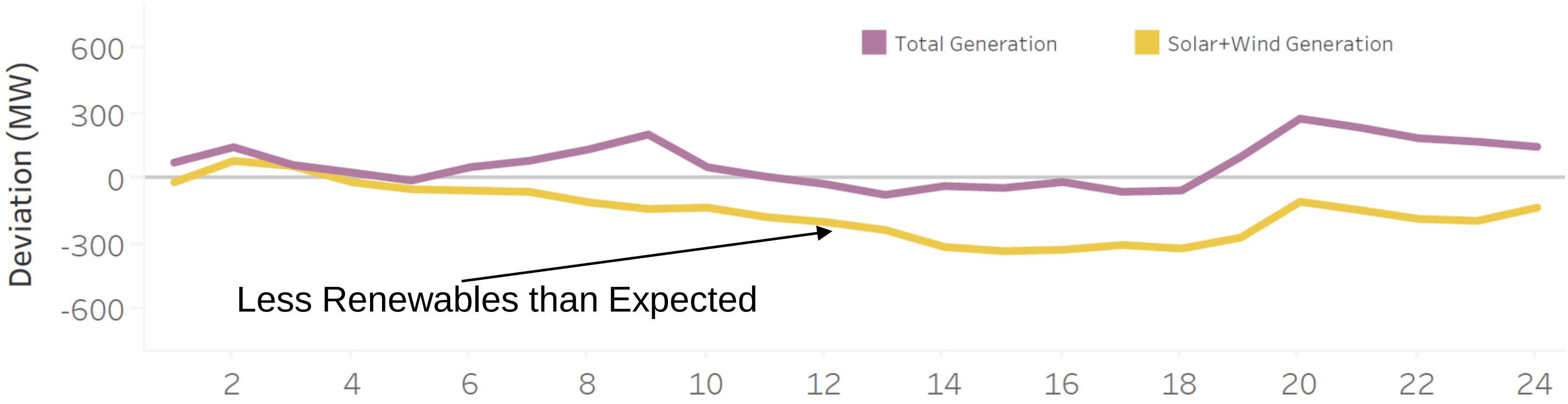
Marginal Costs Overestimated

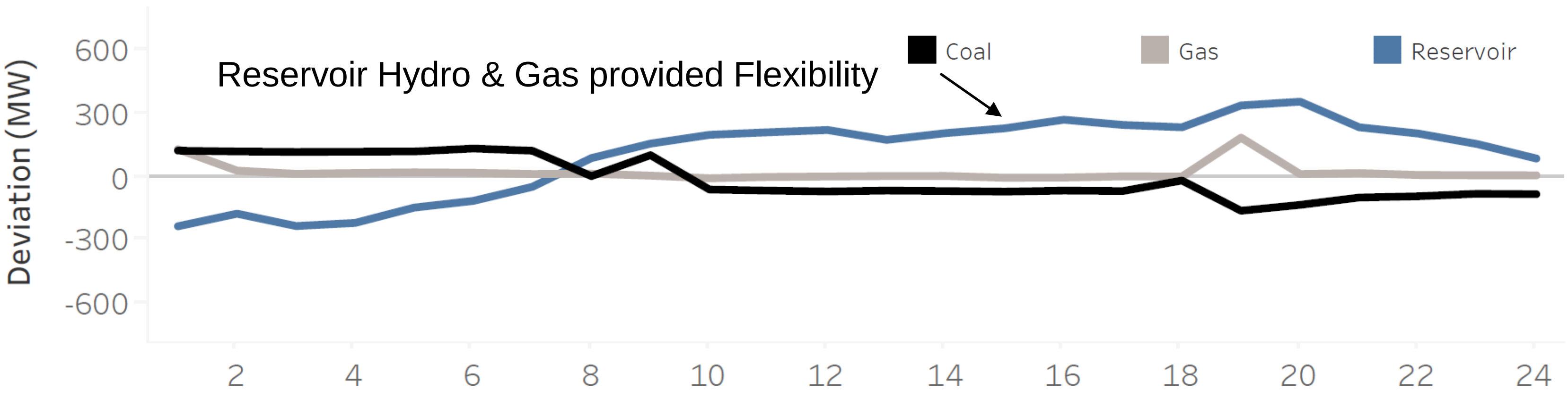
Imports from the SIC provided flexibility & lowered marginal cost between 7pm & Midnight

Programed SING to SIC but flowed from SIC to SING

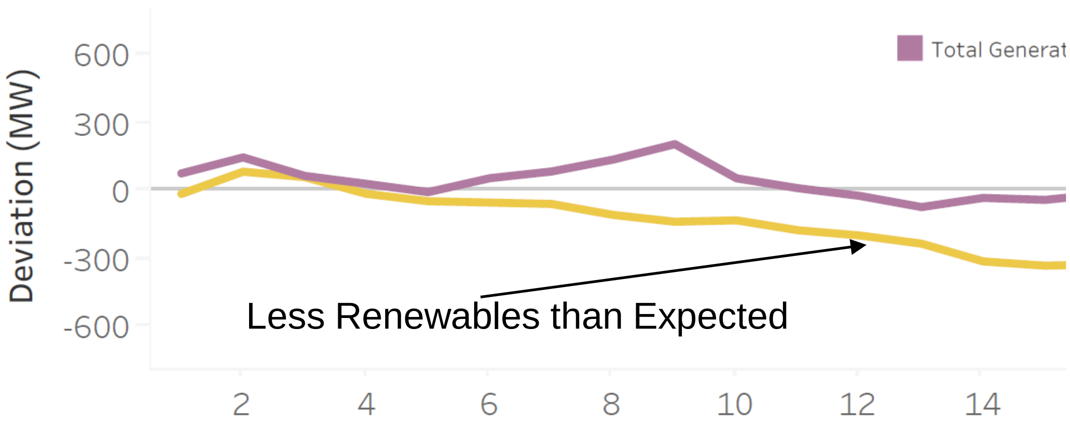


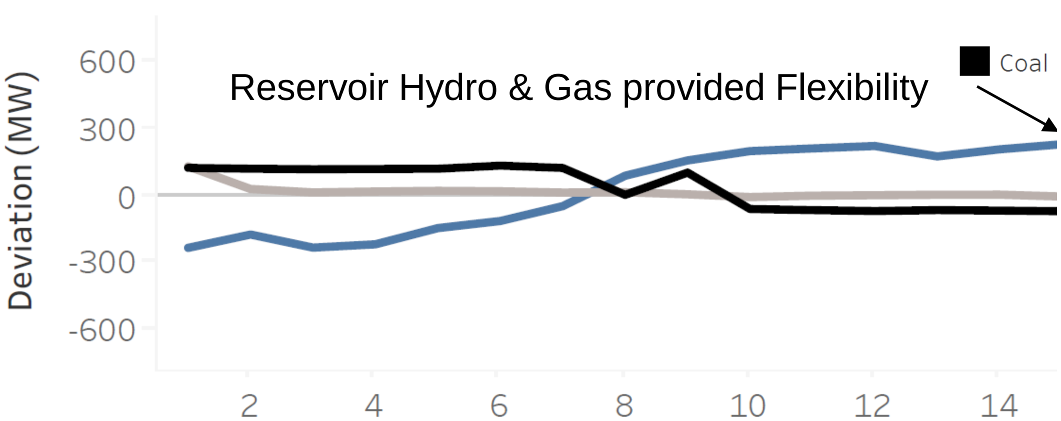
Dynamics of 9-23-2017 SIC (Pre-Interconnection)

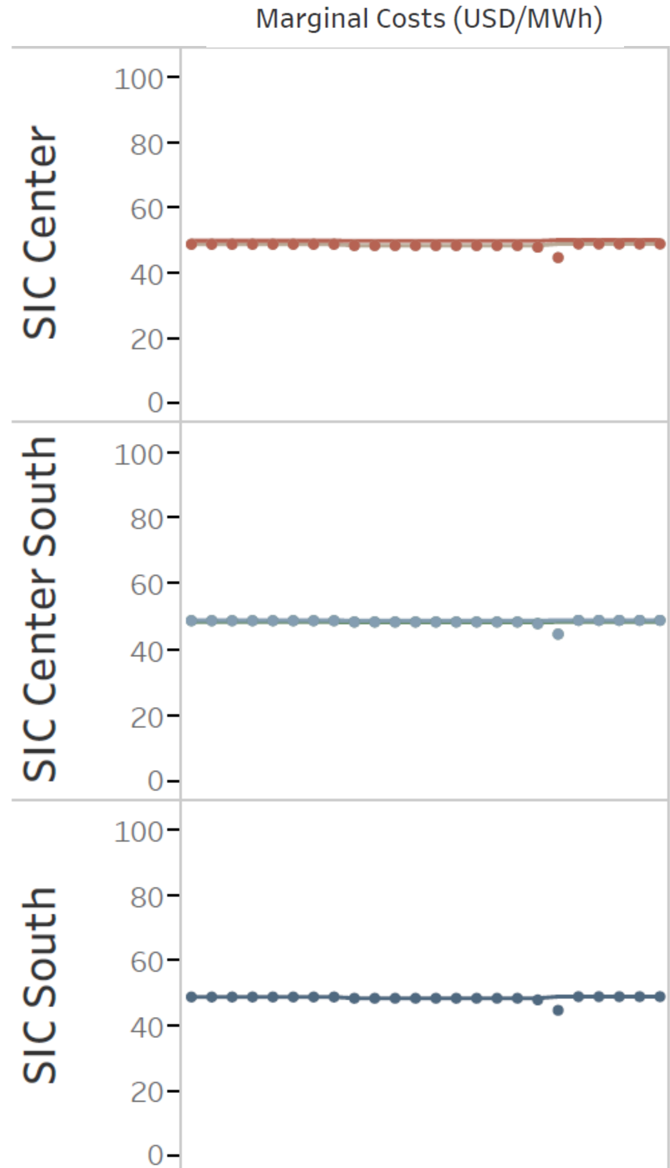




Dynamics of 9-23-2017 SIC (Before Interconnection)







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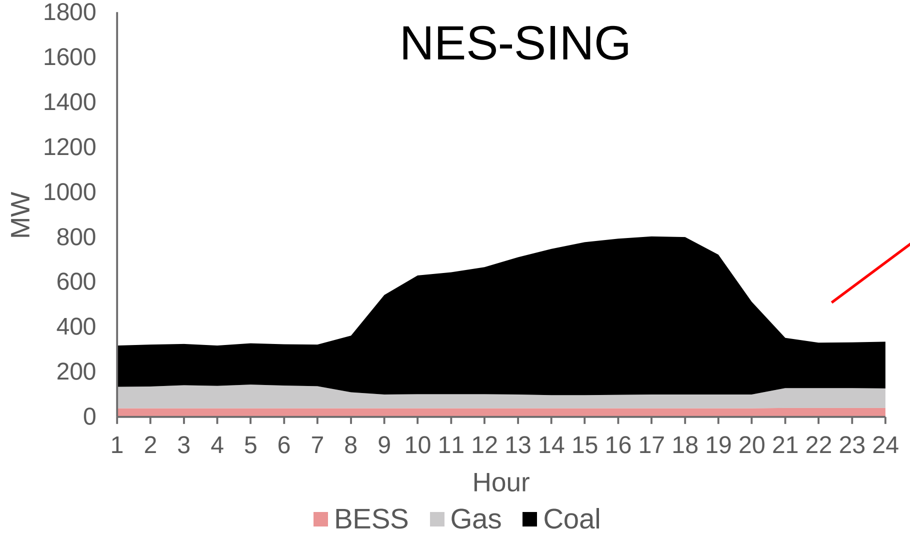
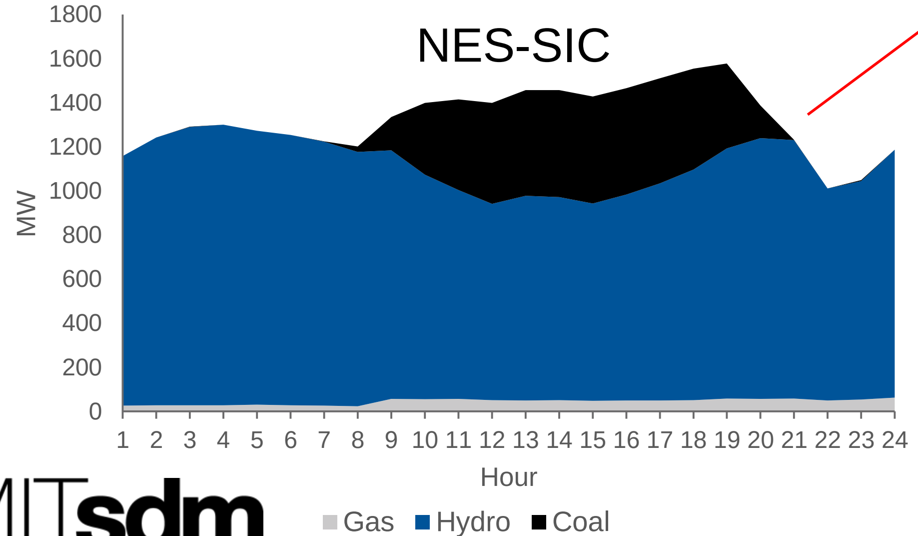
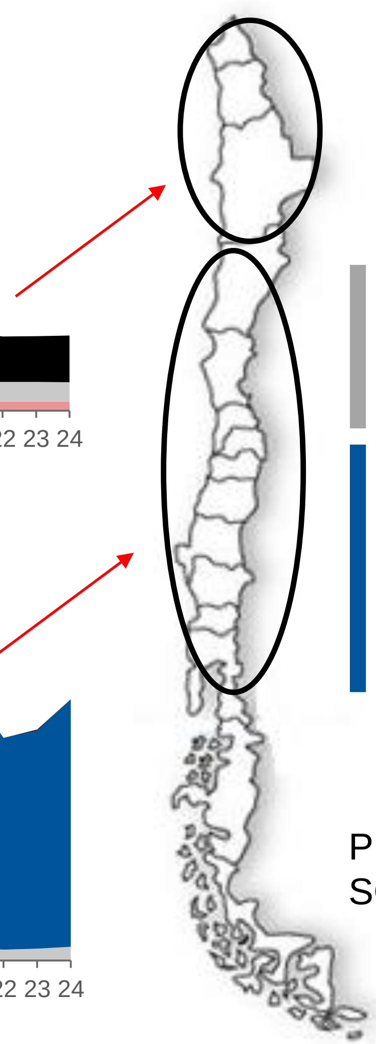
Overview of Planned Reserves for Frequency Regulation:

PFC (Contingency) + PFC (Up Regulation) + SFC (Up)

Case December 2017 (average day)







Recently, the interconnection (NES-SIC & NES-SING) allowed the reduction of reserve requirements for PFC in the system.

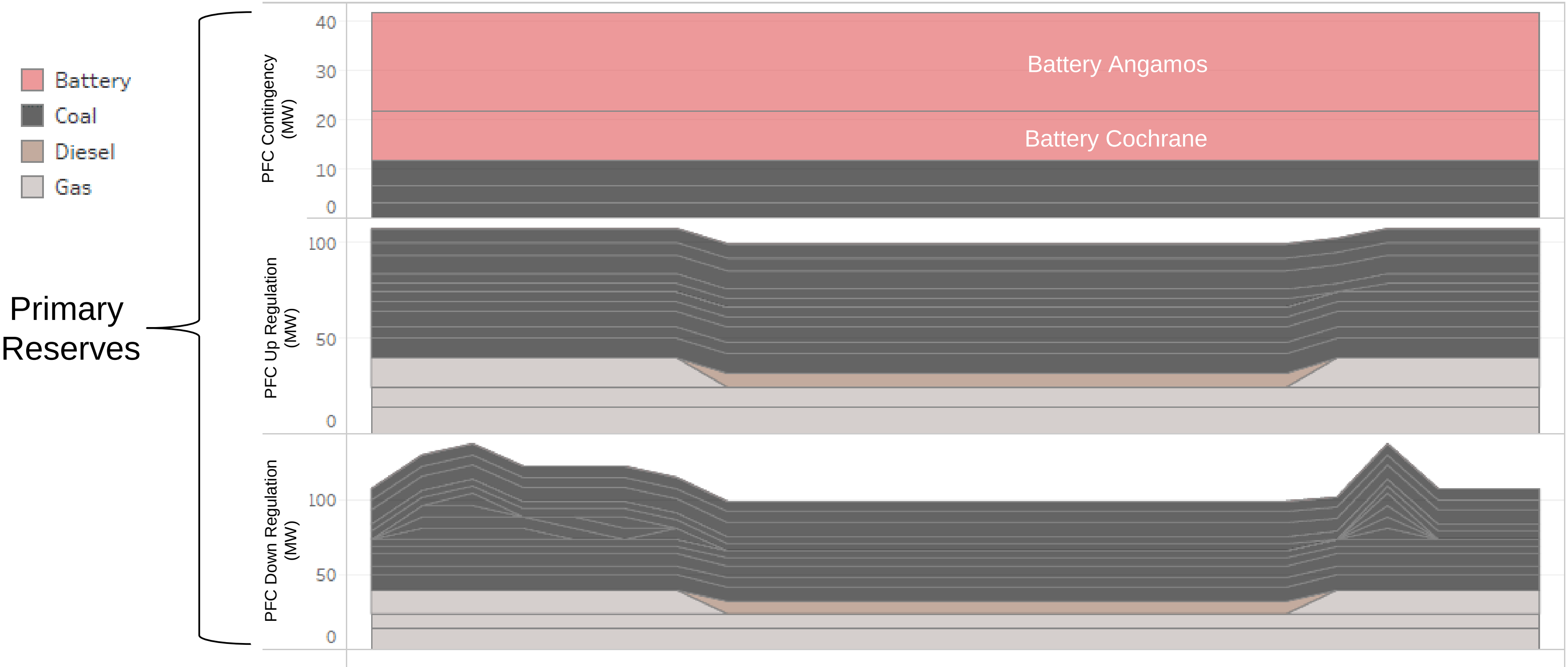
Different reserve providers in the SIC-Center and SIC-South.

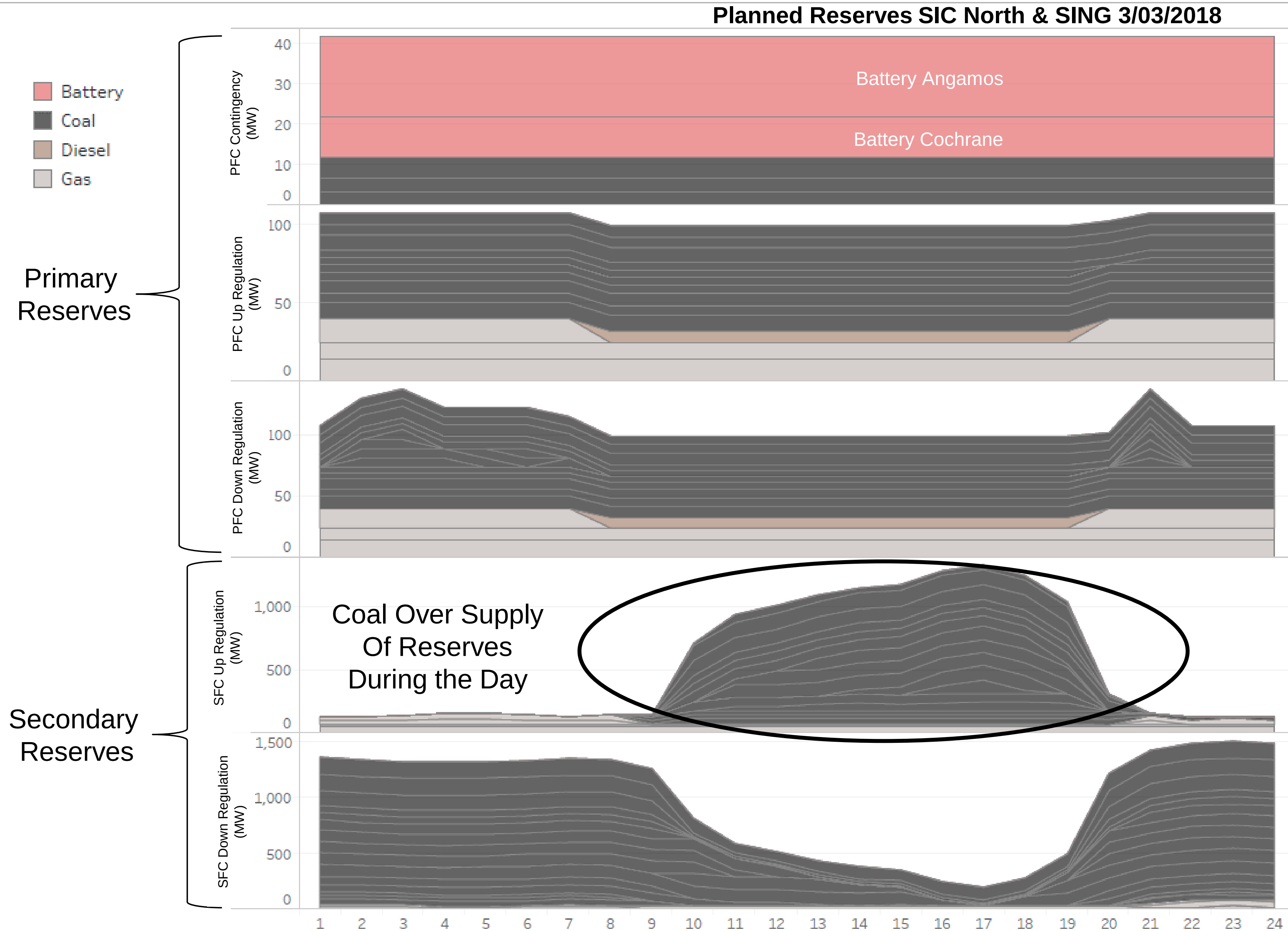
Competitive advantage of generators that provide reserves in different regions of the NES-SIC.

PFC: Primary Frequency Control
SCF: Secondary Frequency Control

Planned Reserves SIC North & SING 3/03/2018

Primary Reserves




Planned Reserves SIC North & SING 3/03/2018
Battery
Coal
Diesel
Gas
Primary Reserves
Secondary Reserves
PFC Contingency (MW)
PFC Up Regulation (MW)
PFC Down Regulation (MW)
SFC Up Regulation (MW)
SFC Down Regulation (MW)
Battery Angamos
Battery Cochrane
Coal Over Supply Of Reserves During the Day
40
30
20
10
0
100
50
0
100
50
0
1,000
500
0
1,500
1,000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

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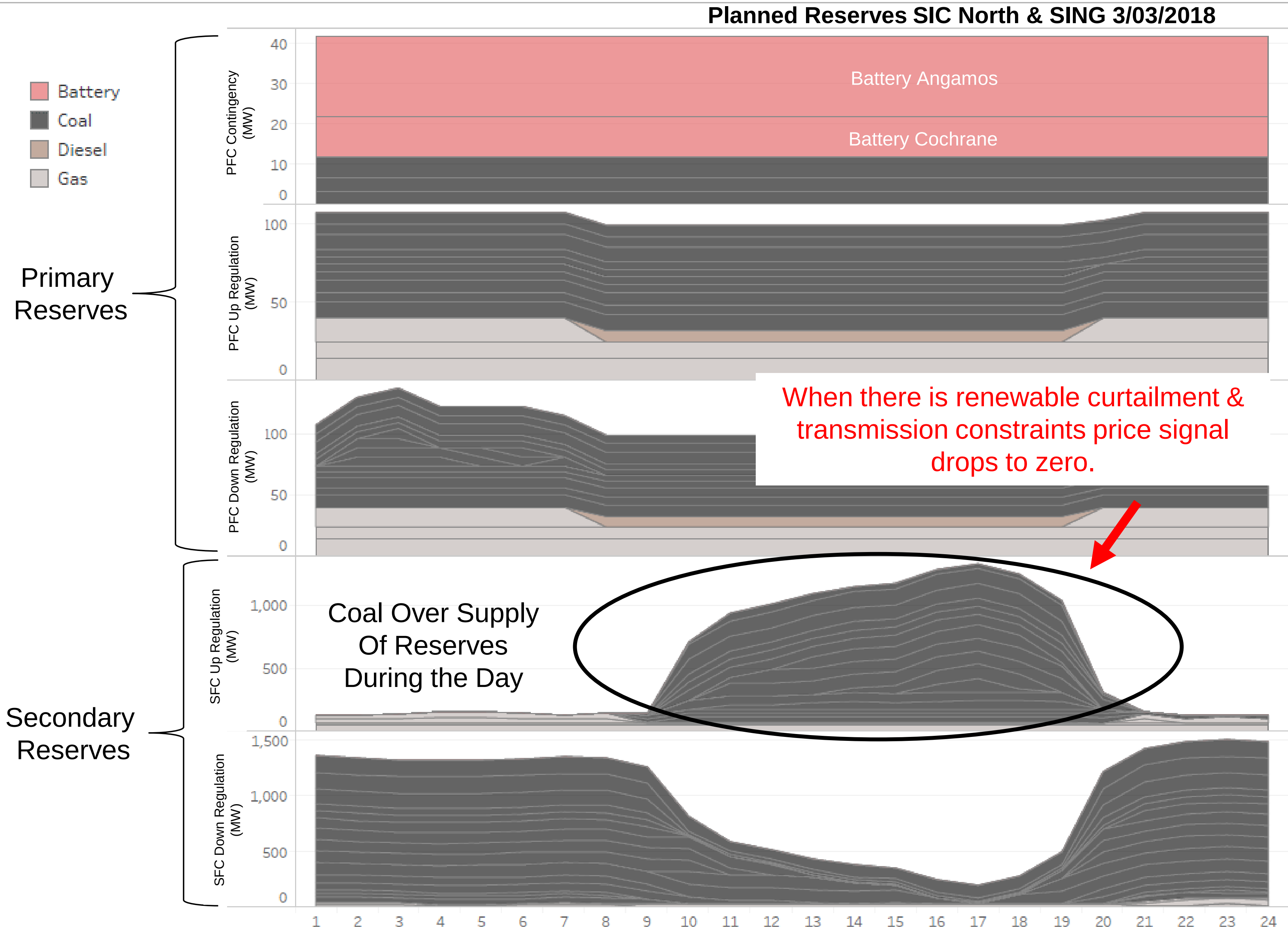
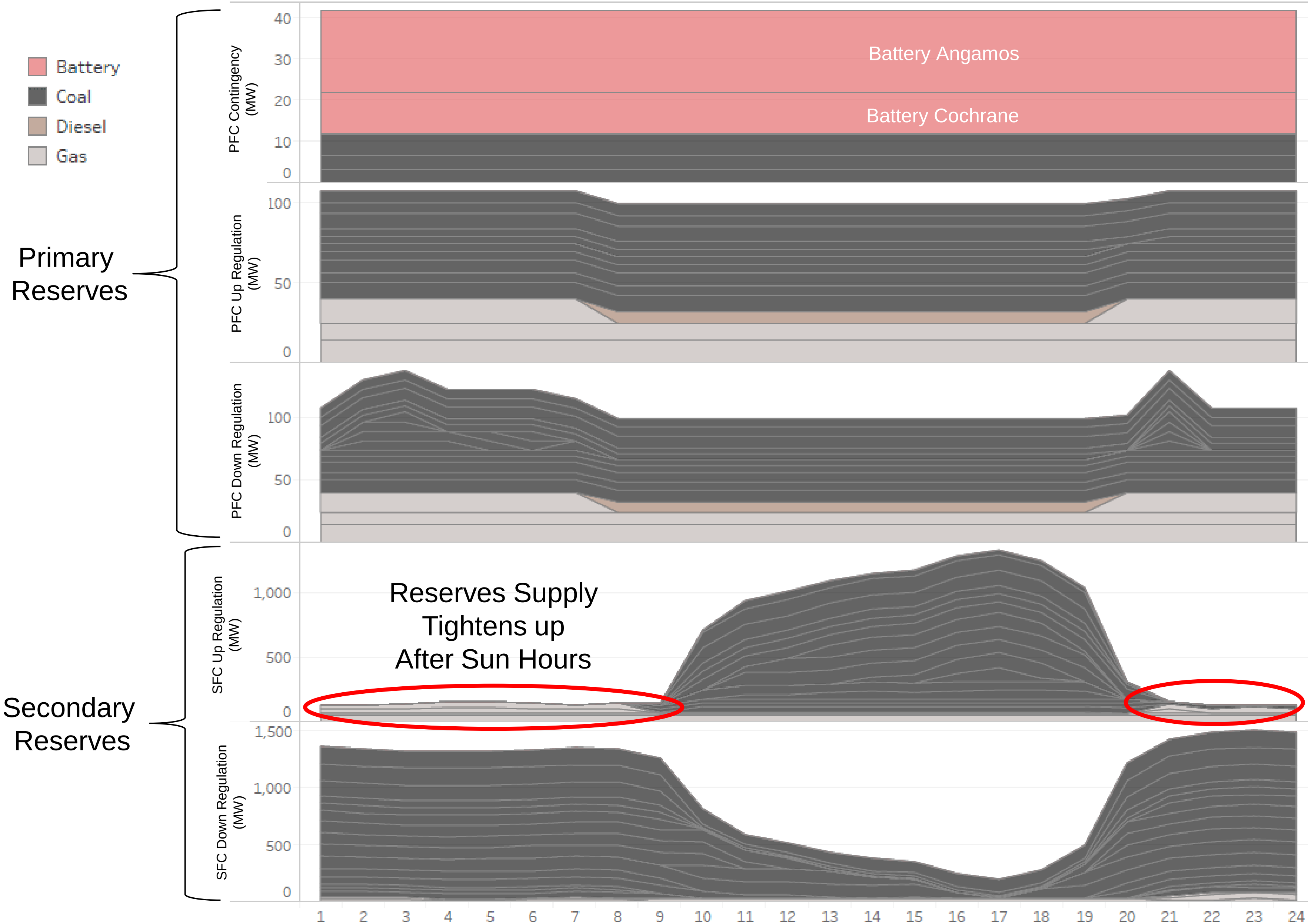
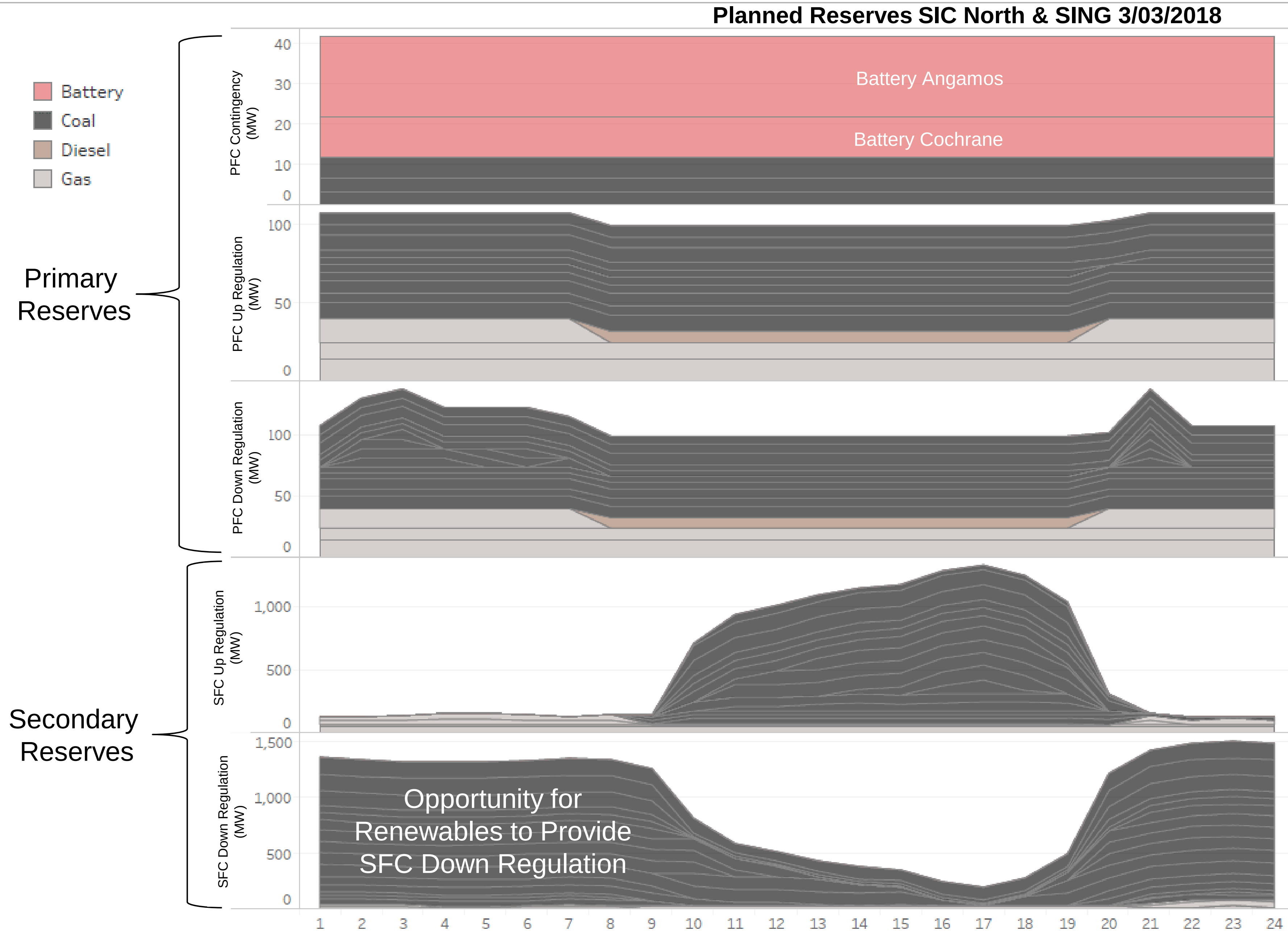


Planned Reserves SIC North & SING 3/03/2018
Battery
Coal
Diesel
Gas
Primary Reserves
Secondary Reserves
PFC Contingency (MW)
Battery Angamos
Battery Cochrane
PFC Up Regulation (MW)
PFC Down Regulation (MW)
When there is renewable curtailment & transmission constraints price signal drops to zero.
SFC Up Regulation (MW)
Coal Over Supply Of Reserves During the Day
SFC Down Regulation (MW)

Planned Reserves SIC North & SING 3/03/2018





Planned Reserves SIC North & SING 3/03/2018
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Gas
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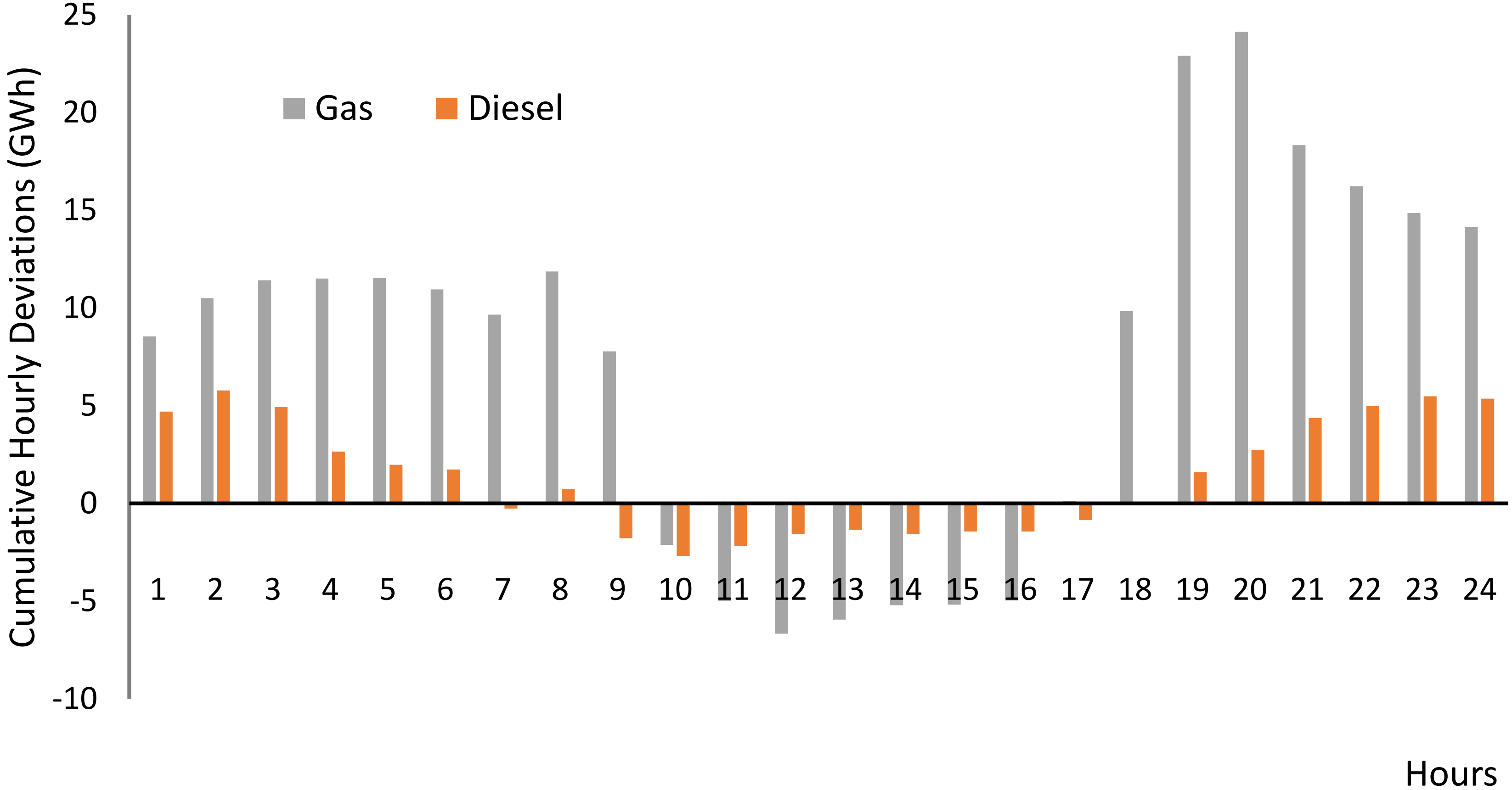
PFC Contingency (MW)
Battery Angamos
Battery Cochrane
PFC Up Regulation (MW)
PFC Down Regulation (MW)
SFC Up Regulation (MW)
SFC Down Regulation (MW)
Opportunity for Renewables to Provide SFC Down Regulation

Use of More Gas and Diesel than Planned in Day Ahead Coincide with Tightening of Reserve Supply

October 2016 – September 2017 (SING)



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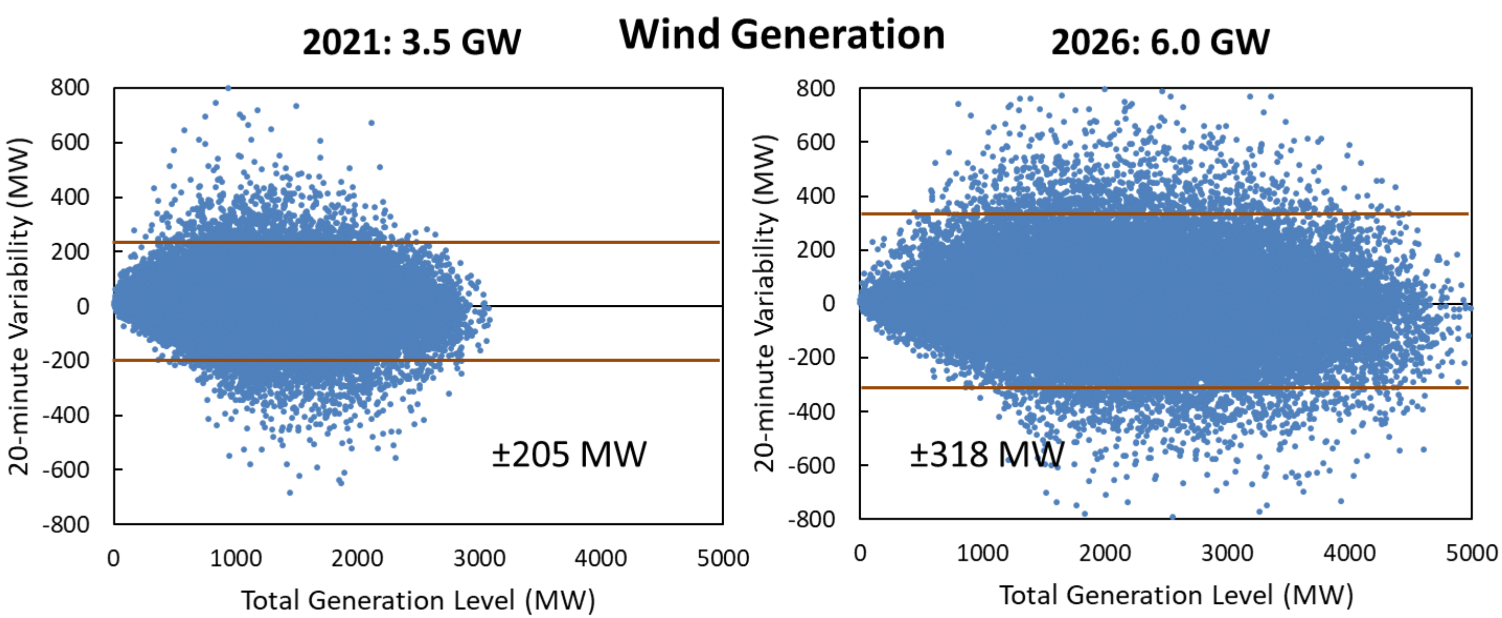
Increases in Wind Capacity Drives New Ramping and Reserve Requirements

- Projected Variability will Drive Definitions of Reserves
  - Scenario for 20-min variability
  - Wind generation developed across Chile



Wind Data: AWS Truepower

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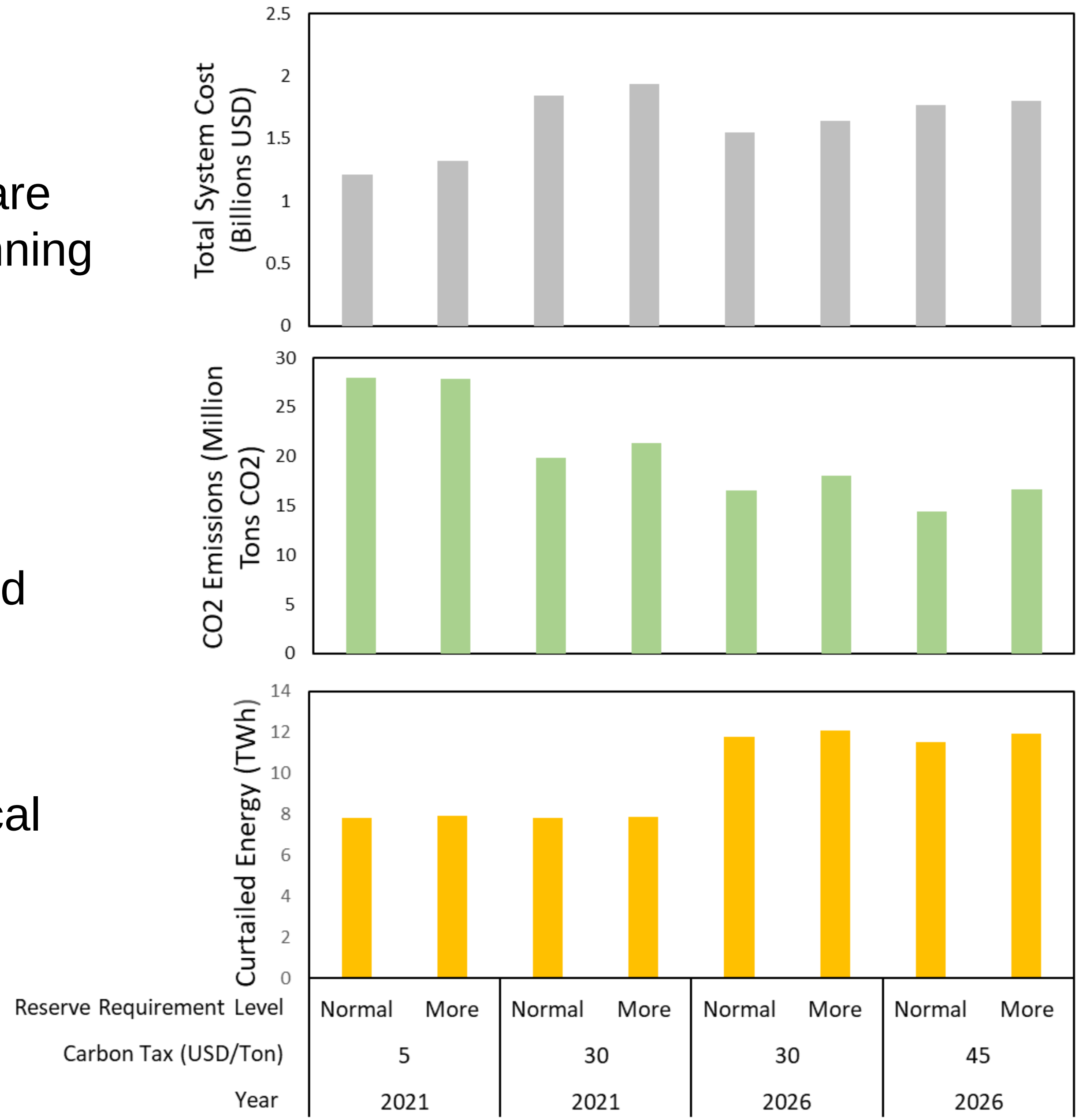
If **no new flexible generation projects** are added, increasing spinning reserve requirements increases:

1. VRE Curtailment,
2. CO2 Emissions, and
3. Operational Costs

for Medium Hydrological Conditions



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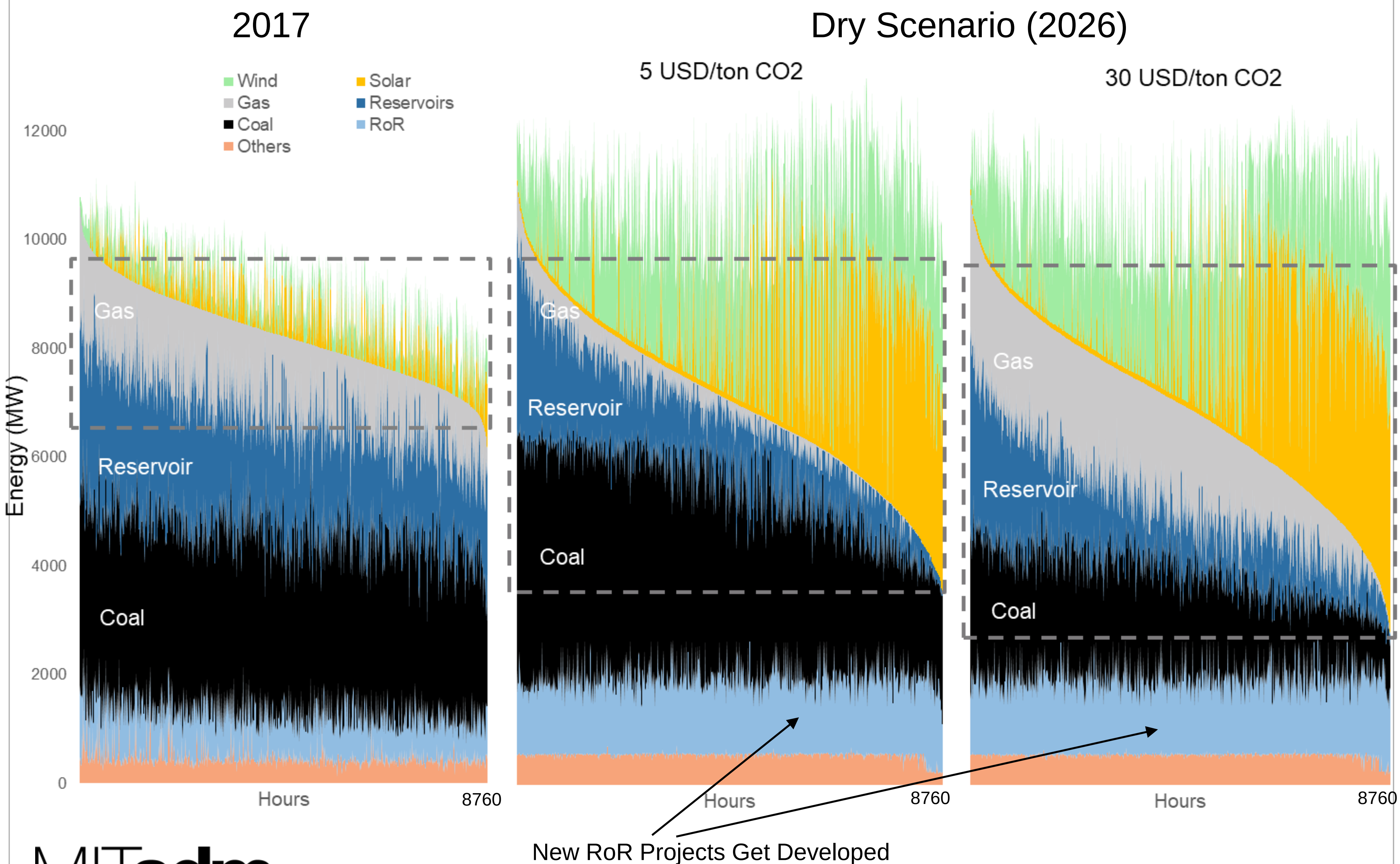
Agenda

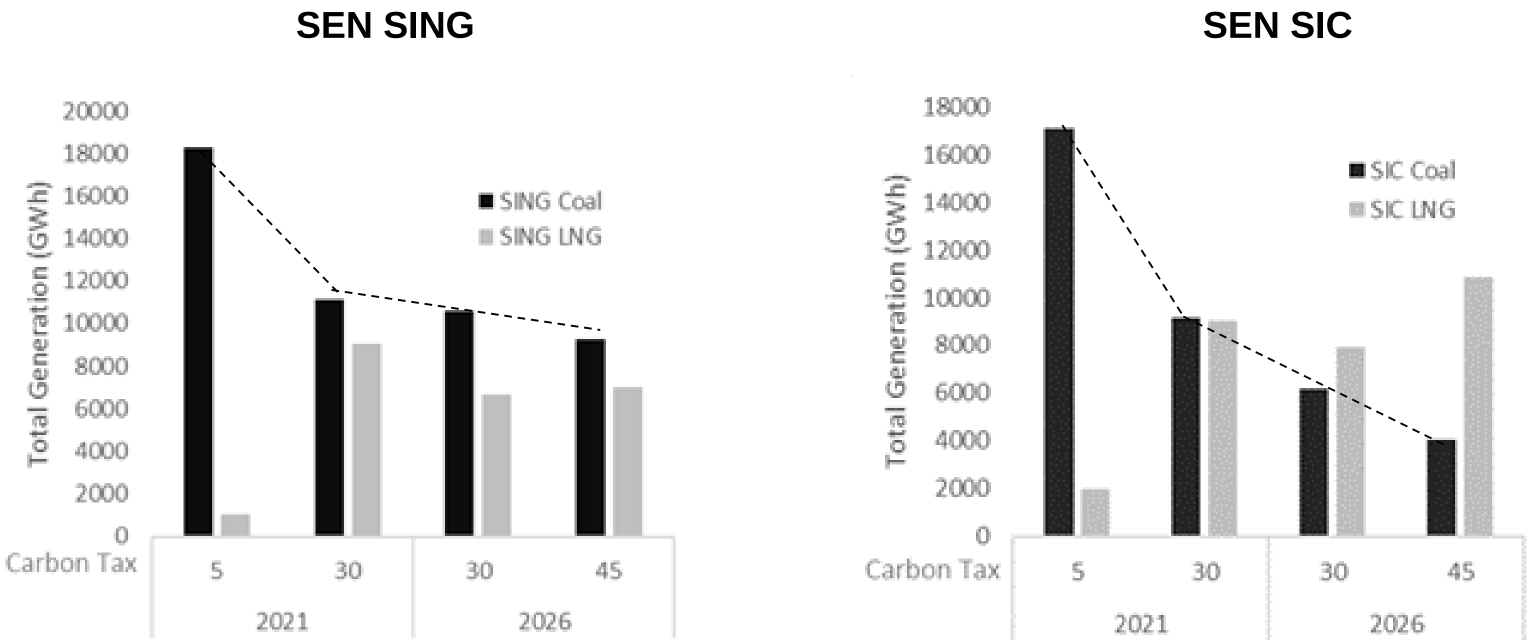
- Trends in Wind & Solar Integration in Chile
- **Emerging Dynamics in the Power System**
  - Changes in the Net Load
  - Regionalization of Power System Dynamics
  - New Modes of Operations of Existing Units
  - Emerging Socio-Technical Constraints
  - Real Time Deviations from the Day Ahead Plan
  - Challenges to Operations of Reserves
  - **The Interactions between Carbon Policy & the Power Market**
- Opportunities to Utilize Existing Flexibility & Encourage Investment in New Flexibility

Effects of Carbon Policy on the Middle Market



Increasing the Carbon Price Does Not Have the Same Effects on the SIC and the SING

(Dry Scenarios)



Flexibility of reservoir hydro & reservoir hydro's ability to provide reserves allows CO2 price signal to be more effective in SIC

Agenda

- Trends in Wind & Solar Integration in Chile
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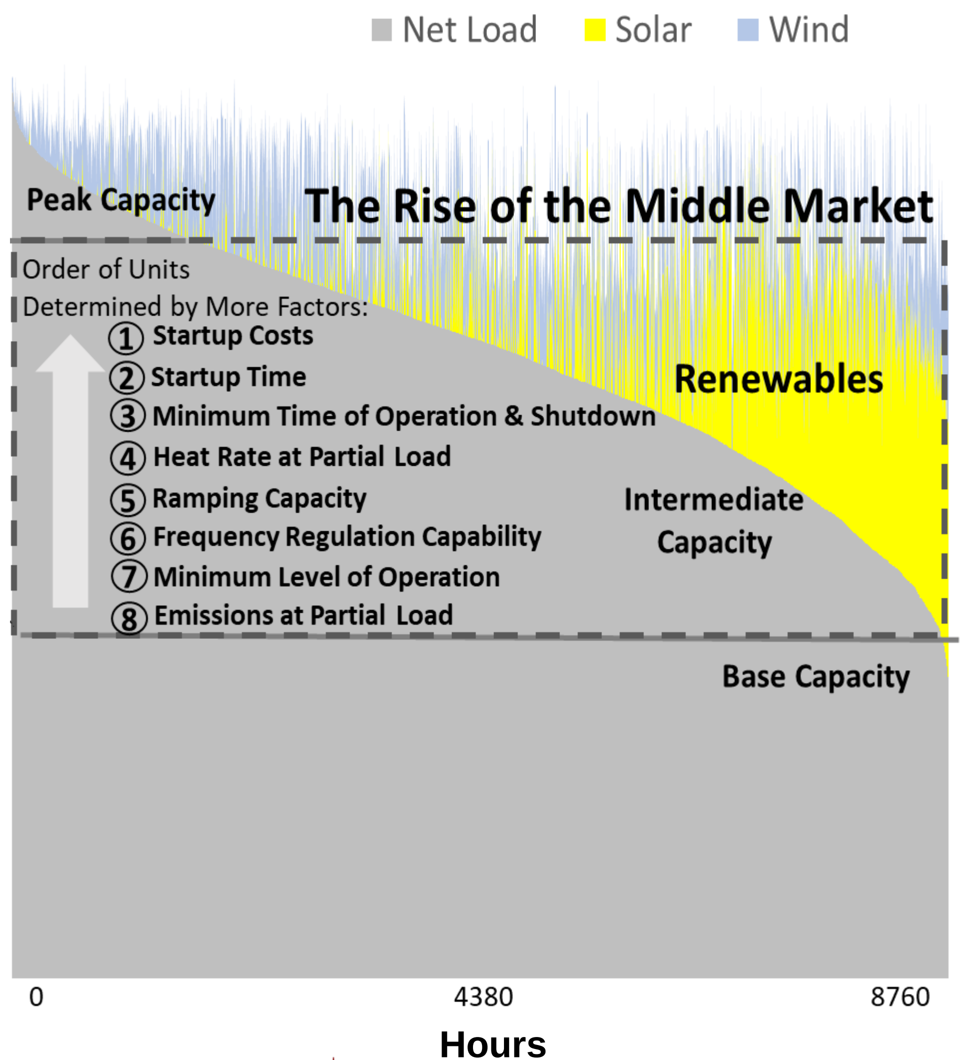
Integration of Solar & Wind will Give Rise to the "Middle Market"

Capacity requirements are changing with emerging flexibility needs

Today, flexibility isn't being fully remunerated.

How will Chile keep integrating more renewable energy efficiently and effectively?

Over time, how will Chile efficiently and effectively replace its existing thermoelectric assets with newer more flexible assets?



New Modes of Operation Increase Costs for Existing Units Creates Opportunities for New Technologies

Type of Unit	Case Summary	Time Operating (hrs)	Starts	Trips	Total Variable O&M (VOM) Cost* (USD/MWh)
280 MW – Coal Unit	**Case 1 –** Plant Operating at Full Load with an Average Time per Cycle of 1875 hrs	7500	Limited	4	2.5
	Case 2 – Daily Cycling between technical minimum and full load.	7116	Limited	4	2.6
400 MW - CCGT Unit	**Case 1 -** Mostly Full load operating 6000 hrs.	6000	Limited	4	3.2
	Case 2 - 150 real starts per year from start to load following.	4000	150 Warm Starts	8	**6.1**
	Case 3 - 300 real starts per year from start to load following.	4000	300 Warm Starts	8	**8.8**

The Policy Levers to Incentivize Investment into New Flexibility Options for the System are Intertwined

Long Term Contracts

Energy Market

CO_2 Policy

Environmental Regulation

Capacity Market

Ancillary Services Market

TX & Dist Planning

Demand Side Policy

Focusing on just improving the parts of the policy independently will not guarantee improving the performance of the whole

The performance of the electricity system will depend on how the policy levers fit together not what they achieve separately

The improvement of the performance of the Electricity System will not be driven by pondering about the future, but rather really understanding what is happening today to find opportunities to improve the system for the long term.

Key Areas to Observe to Find Opportunities for Flexibility:

1. Performance of existing thermoelectric facilities
2. Variability & deviations from the planned
3. Deviations between actual & expected economic performance of the system
4. New constraints which emerge as the system operates
5. The behavior of the "Middle Market" & its interaction with Environmental restrictions & CO_2 Policy
6. Interactions between energy and operating reserve services
7. Performance parameters which will be more relevant to address new challenges such as satisfying the net-load or improving regional needs

Upcoming Related Presentations & Paper

watercongress
6th International Congress on Water Management in Mining
2nd International Congress on Water in Industrial Processes
May 9-11, 2018 | Santiago, Chile

Presentation of New Methodology to Asses Environmental Impact Industrial Facilities in Chilean Environmental Impact Assessment System

Jorge Moreno, Partner at inodú
Donny Holaschutz, Partner at inodu

MIRECWEEK
21 - 24 May 2018 I MEXICO CITY

Teaching Masterclass on Opportunities for Storage in Mexico

Donny Holaschutz, Partner at inodu

41ST IAEE INTERNATIONAL CONFERENCE
GRONINGEN
10-13 JUNE 2018

NEW MARKET INTERACTIONS IN THE CHILEAN ELECTRICITY SYSTEM WITH HIGH INTEGRATION OF VARIABLE RENEWABLE ENERGY

Benjamin Maluenda, Lead Analyst at inodú
Jorge Moreno, Partner at inodú
Donny Holaschutz, Partner at inodú
Esteban Gil, Professor at Universidad Técnica Federico Santa María

PENREC
PERUVIAN NEW & RENEWABLE ENERGY CONGRESS

Presentation for Opportunities for Renewable Energy in Mining

Jorge Moreno, Partner at inodu

MEGA
Power Plant Pollutant and Effluent Control MEGA Symposium: Best Practices and Future Trends
August 20-23, 2018 • Baltimore, MD

Challenges Complying with Emissions Limits in Chile Caused by New Modes of Operations and High Levels of Renewable Energy Integration

Jorge Moreno, Partner at inodú
Donny Holaschutz, Partner at inodu

system design & management

Renewable Energy Integration Opportunities & Challenges in Chile

MITsdm

Jorge Moreno SDM 2011
Donny Holaschutz SDM 2010