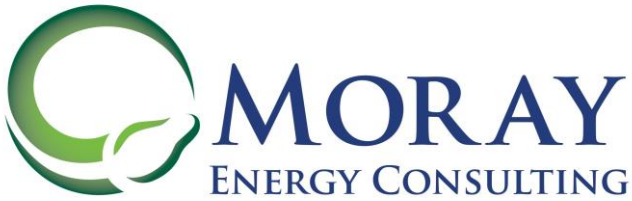
Flexibility costs under high variable renewable energy generation: *the Chilean case*

S. Mocarquer, R. Quinteros, S. Binato, M. V. F. Pereira

2018 IEEE GENERAL MEETING

Portland, August 2018



Overview

- Objectives of the Analysis
- Chilean Market Overview
- Methodology
- Results
- Conclusions

Objectives

- Quantify the effects of massive VRE[1] insertion in the operation of the electric system with focus on 'Flexibility Costs'
- Provide valuable inputs for the regulatory discussion in Chile
- The study was commissioned by the Chilean Generators Association (AG)

Generadoras de Chile

AES Gener energía confiable · ENGIE · GPG global power generation · PacificHydro

AME · Colbun · EDF · PrimeEnergía

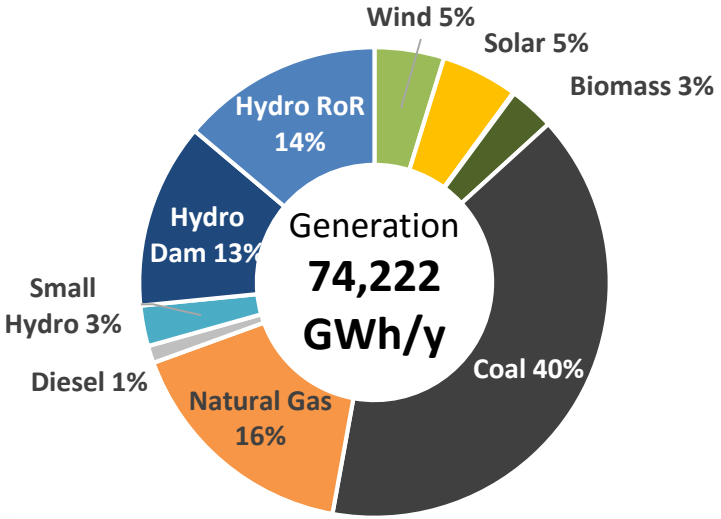
CERRO DOMINADOR CONCENTRATED SOLAR POWER · enel · Orazul ENERGY · Statkraft PURE ENERGY

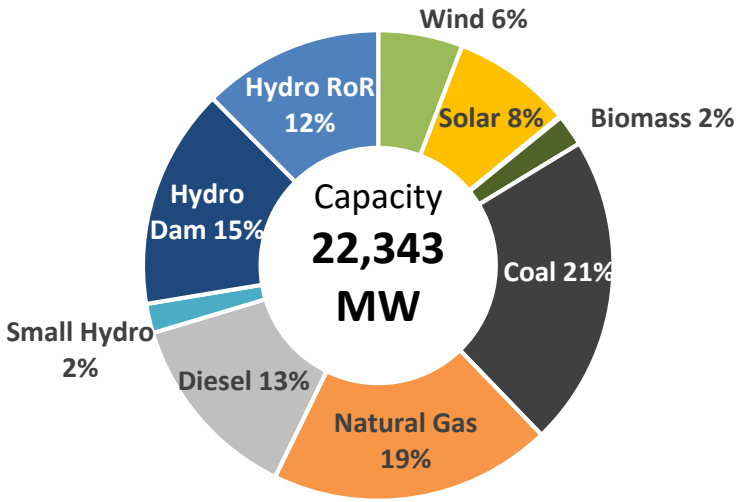
- Independent analysis based on public information

Note: (1) VRE: Variable Renewable Energy (Solar, Wind)

Chilean Market Overview

Key information 2017	
Renewable generation	15% (excluding large hydro)
Peak demand	10,363 MW
Energy Sales	49% regulated, 51% un-regulated
Transmission lines	32,100 km
GDP per capita (PPP)	US$ 24,085





Source: Annual Energetic Report CEN, January 2018. Installed Capacity SEN, Anuario CNE 2017. GDP, The World Bank.

Consulting Team

MORAY ENERGY

- Consulting firm founded in 2013 by executives from the electricity sector, in Santiago - Chile, to support investors and stakeholders in decision-making in the energy sector.
- Wide range of services taking advantage of extensive experience and high degree of specialization;
  - Market and regulation analysis
  - Business strategy
  - Due diligence for transactions
  - Business development

www.morayenergy.com

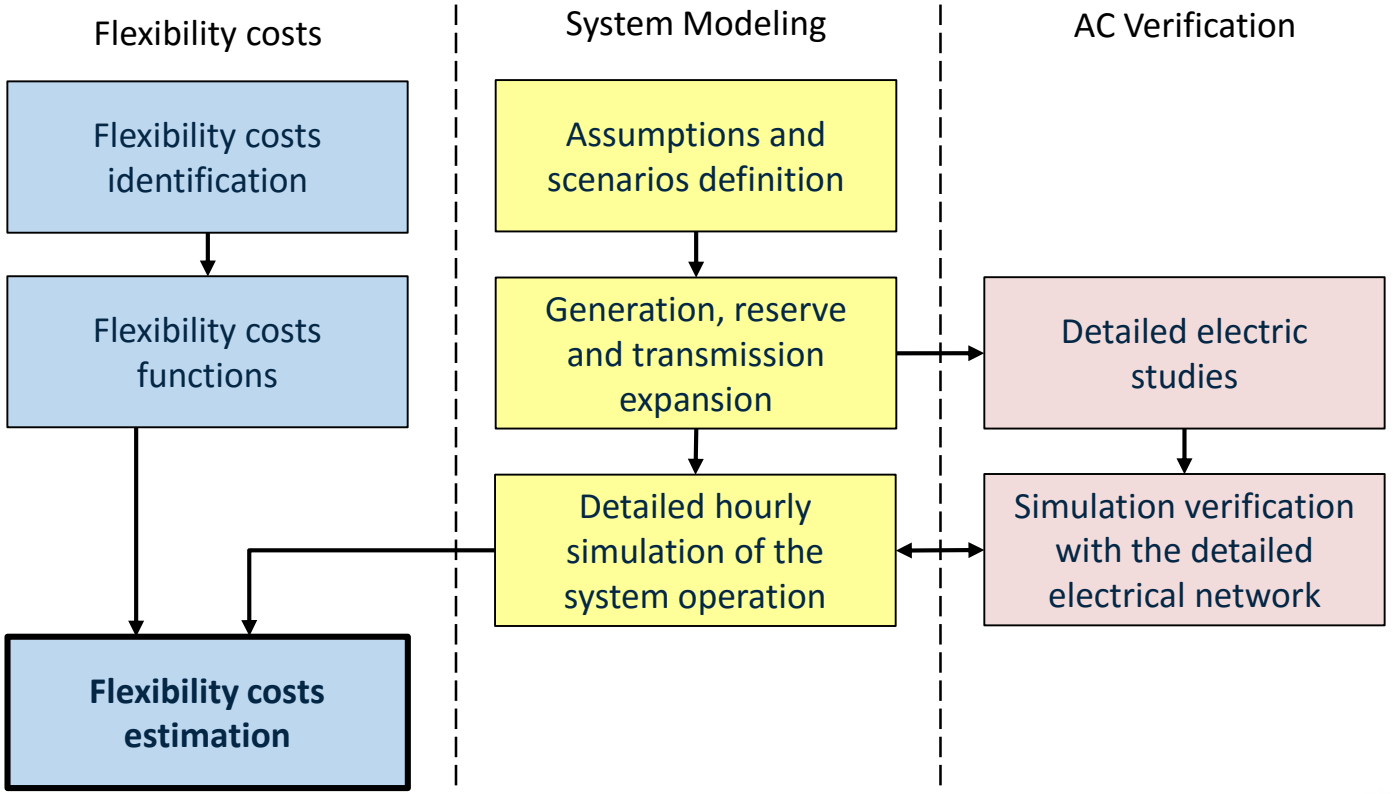
PSR

- Provider of analytic tools and consultancy (economic, regulatory and financial studies) in electricity and natural gas since 1987, based in Rio de Janeiro – Brazil.
- Team of 54 specialists (17 PhDs, 31 MSc) in engineering, optimization, energy, statistics, finance, regulation, IT and environmental analysis.
- In more than 70 countries on all continents.

www.psr-inc.com

Methodology of the study

- The aim was to estimate the flexibility costs associated with different VRE (solar-wind) expansion scenarios



Modeling Tools: PSR Core planning system

PSR Cloud

ePSR: Information management environment

HERA
Inventory of hydro basins and other renewable resources

OptGen/OptFolio
Integrated generation / interconnection / reserve expansion + financial analysis

NetPlan
Detailed probabilistic transmission and VAr planning

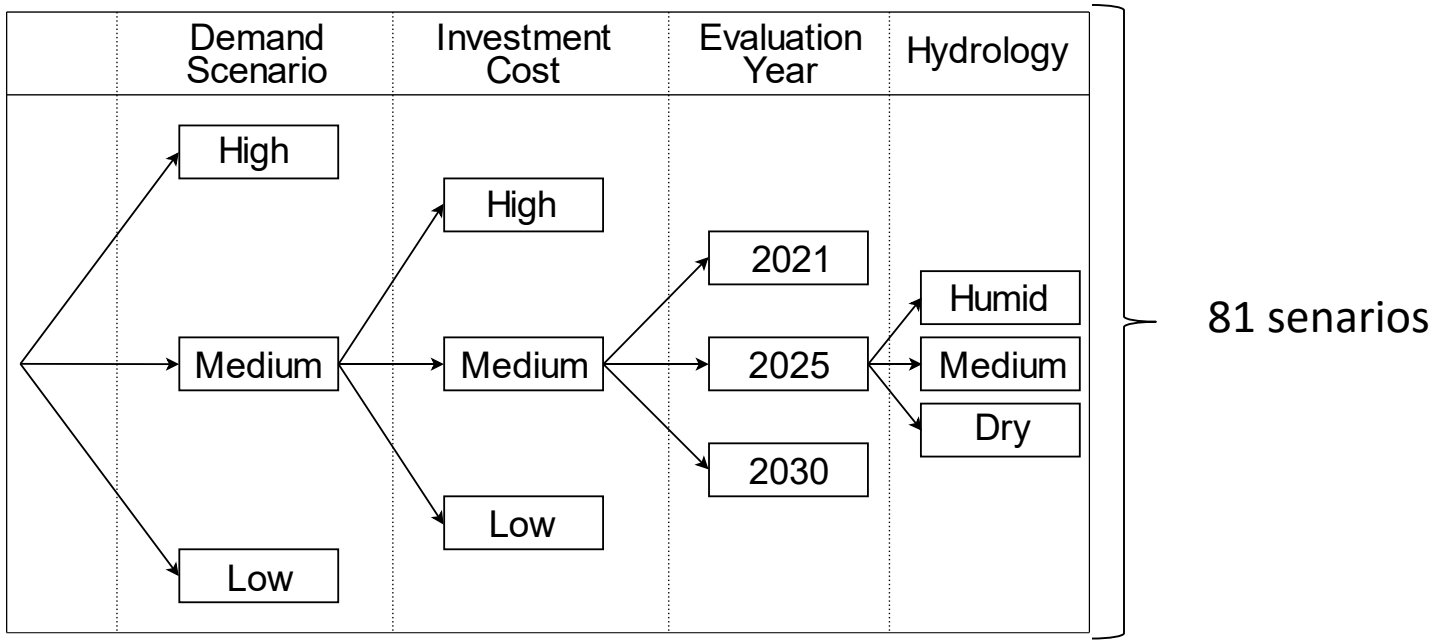
Time Series Lab
Multiscale stochastic scenarios (inflow, renewable, demand)

SDDP/NCP/CORAL
Probabilistic hourly simulation of system operation and G&T supply reliability evaluation

OptFlow
Optimal Power Flow linearized active power w/ losses and full AC model

Scenario Definition

- VRE insertion level was driven by investment costs and demand scenario

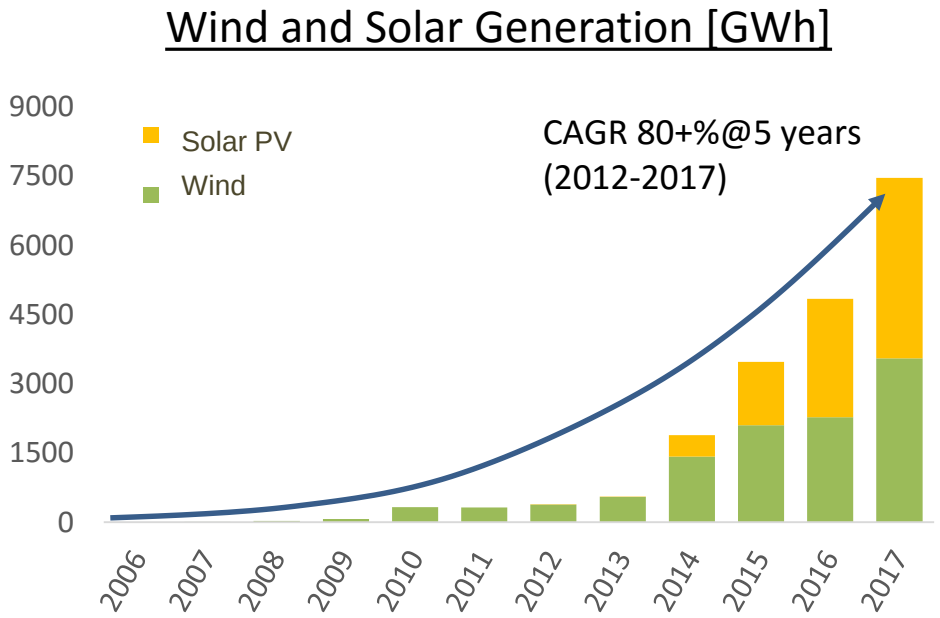


Scenario coding: D*X*C*Y* – Plan with demand scenario *X* and investment costs *Y*

- *X*: *A* (high demand), *M* (average), *B* (low)
- *Y*: *A* (high price); *M* (average); *B* (low)

Flexibility

- Flexibility → ability of the system to efficiently respond to supply and demand imbalances
- Massive insertion of VRE → greater challenges in system operation require system flexibility



Sources of Flexibility

- Generation technologies ← focus of the study
- Demand response
- Storage technologies
- Interconnections

Flexibility Cost Components

- The following flexibility costs were evaluated:

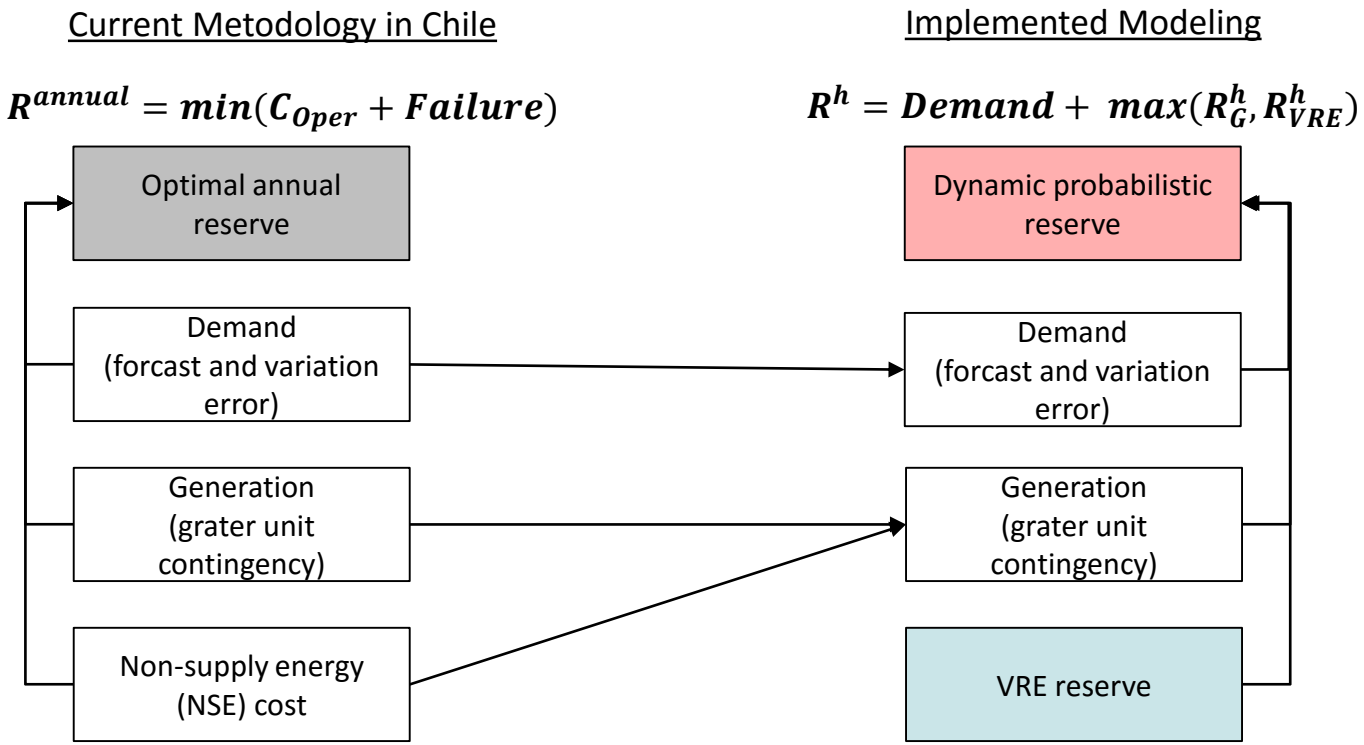
Type of Cost	Components	Function
Direct Start Up Costs	Fuel and emission costs	$f(\#\text{Start Cycles})$
Indirect Start Up Costs	Capex and maintenance	$f(\#\text{Start Cycles})$
Ramp Up/Down Cost	Capex and maintenance	$f(\#\text{Ramp Cycles})$
Efficiency Cost	Fuel and emissions	$f(Dispatch)$
Opportunity Costs	Lost variable margin	$f(Dispatch\ and\ Spot\ Price)$

- Cost functions[1] were applied to output variables obtained from the simulations
- *Ex-post* analysis to assess unrecovered costs under current regulation

Note: (1) The functions related to the start up and ramp up/down costs have been estimated using approximations based on international sources (Power Plant Cycling Costs, NREL, 2012)

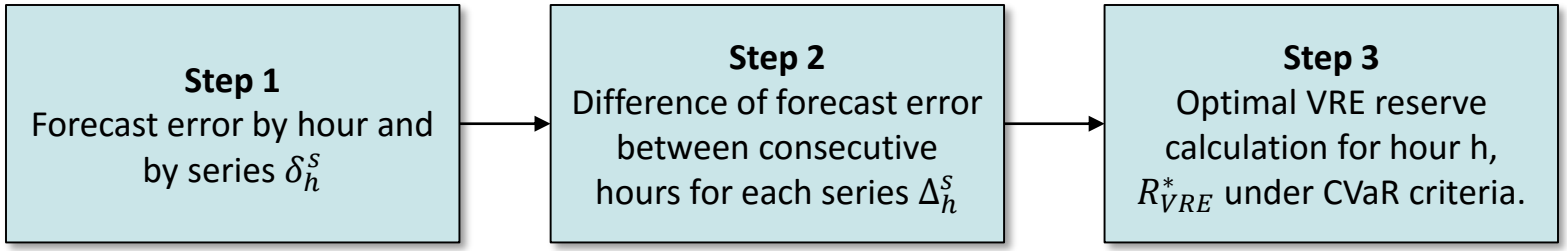
Criteria for operational reserve

- Challenge to incorporate VRE effect to current methodology in use in Chile
  - ➢ R = ƒ(D, G, VRE)



VRE Reserve (R_{VRE})

- Required reserve to account for the uncertainty associated with the forecast error of VRE generation from the simulated series:

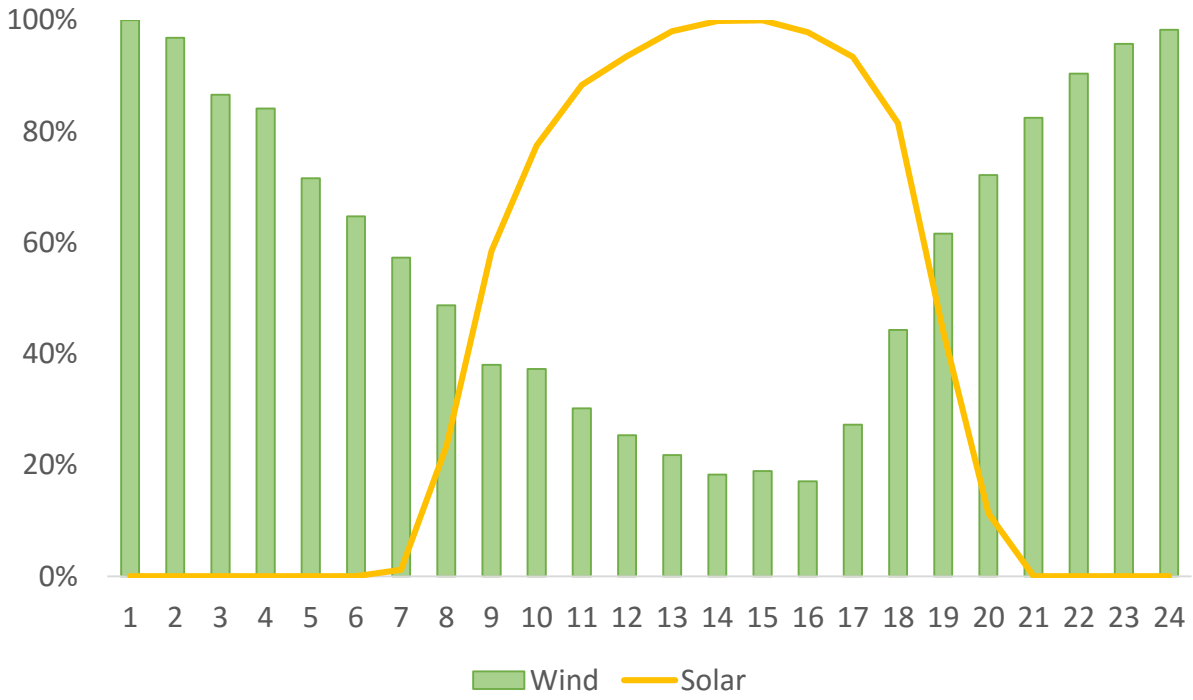


$$R^*_{\mathrm{VRE}} = \lambda \times E(R) + (1-\lambda) \times CVaR_{90\%}(R)$$

- With this type of risk criterion, λ=0.8 represents a reasonable compromise between reliability and cost

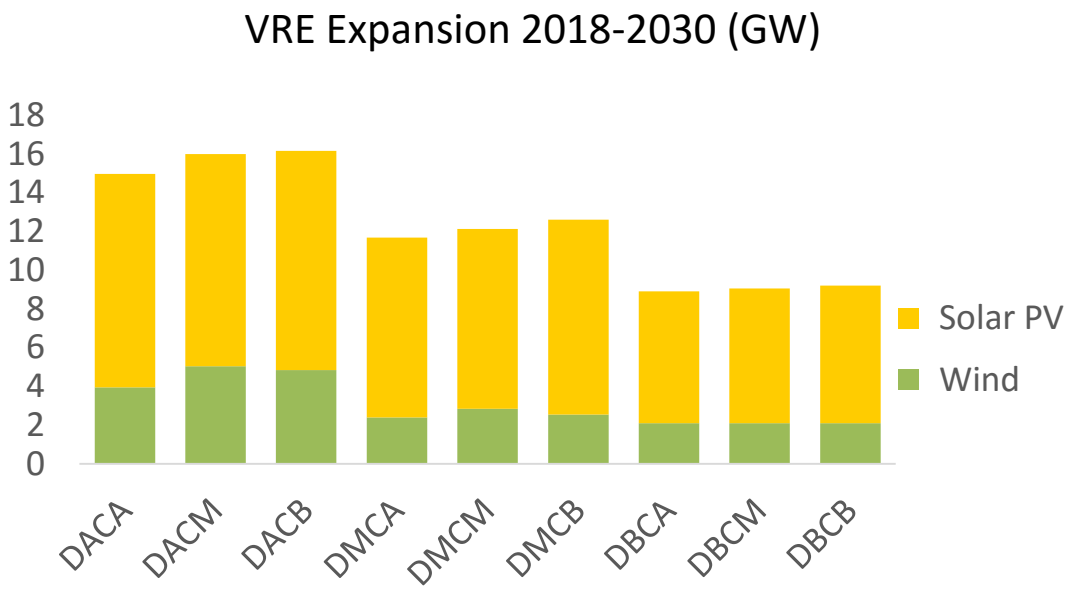
Wind – Solar Complementarity

- The complementarity of the wind and solar generation is captured in the optimized generation expansion considering hourly profiles



Main Results: Generation Expansion

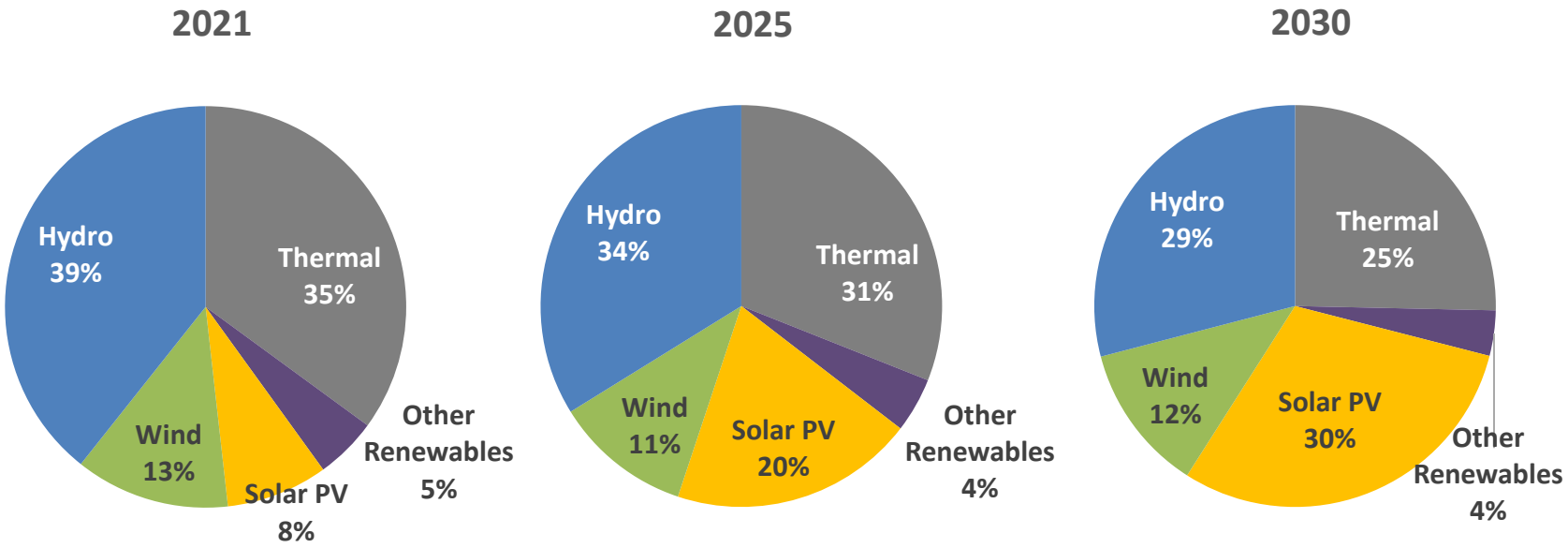
- Wind and solar technologies grow between 9.000 and 16.000 MW by 2030 (investment potential between US$ 8.000 and 18.000+ millions)



- Reserve expansion is identified in the North of Chile (200 – 1.000 MW)

Main Results: Generation by Technology
(Median Hydrology - DMCM)

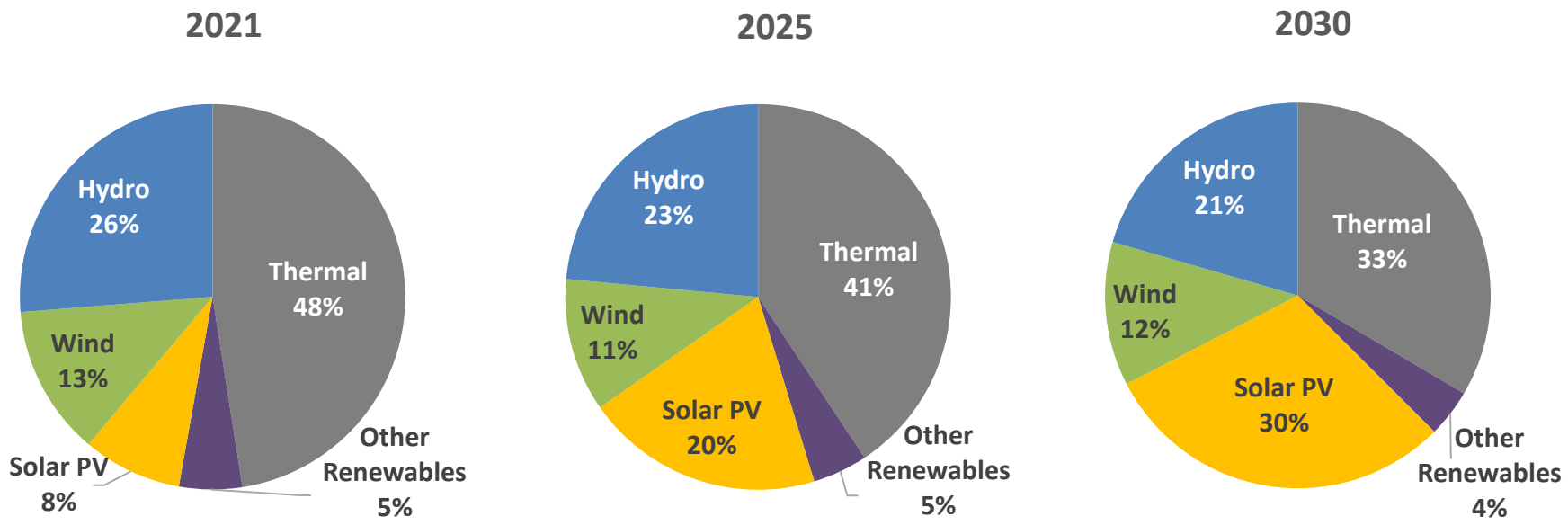
- VRE generation share of 42% by 2030



- Including hydro, renewables account for 75% of energy generation by 2030

Main Results: Generation by Technology
(Dry Hydrology – DMCM)

- Thermoelectricity is still relevant by 2030 under dry hydrology (33% share)

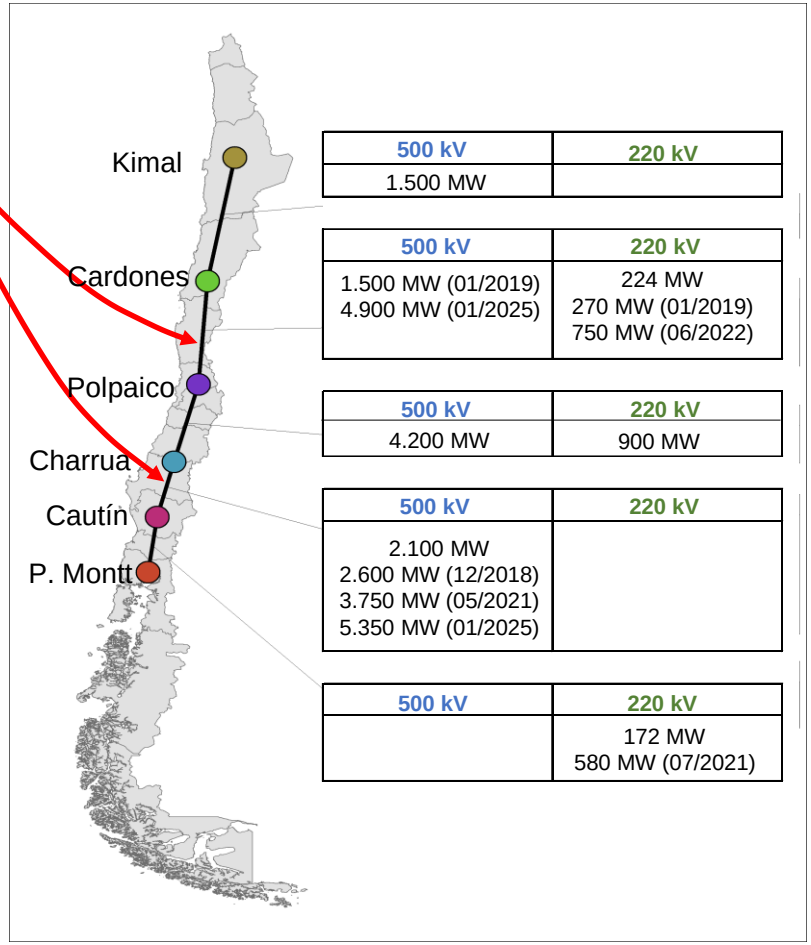


- No decommissioning of coal fired power plants was considered

Main Results: Transmission Expansion

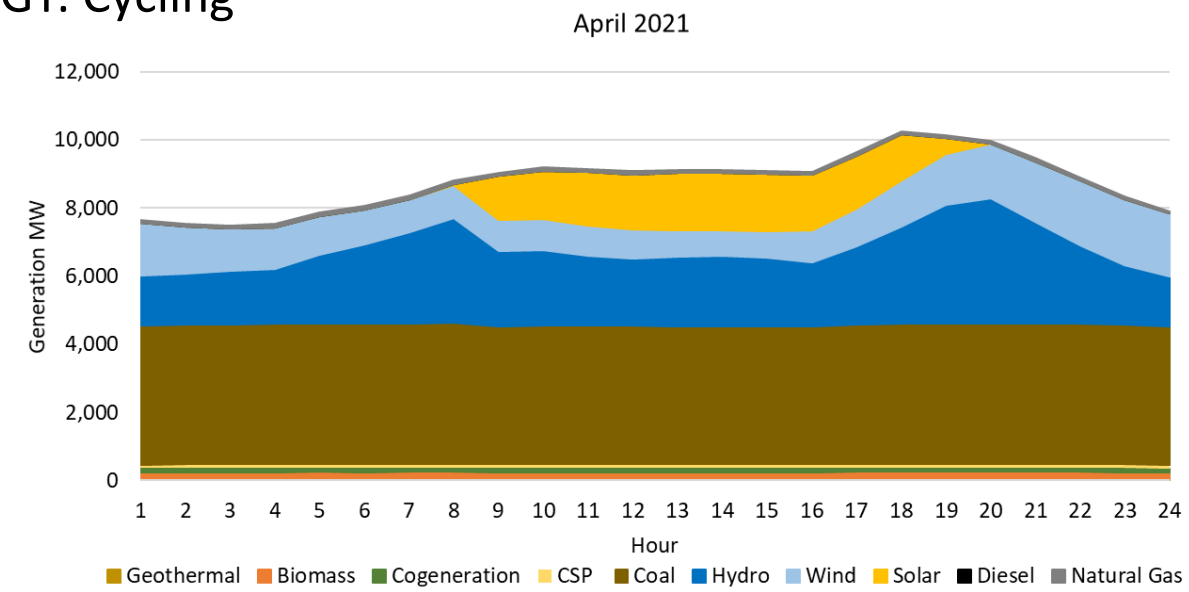
- Relevant capacity expansion is needed at 500 kV level by 2025

- Expansion plan proposed by the Government includes a longer 500 kV HVDC line between Kimal and Polpaico (US$1,8 billion)



Main Results: Daily Dispatch – 2021

- The reservoirs and thermoelectricity will provide flexibility in an increasing manner
  - Hydro Dam: Daily storage (solar hours)
  - Coal: Ramping/minimum operation
  - CCGT: Cycling



Note: Median Hydrology - DMCM

Main Results: Daily Dispatch – 2025

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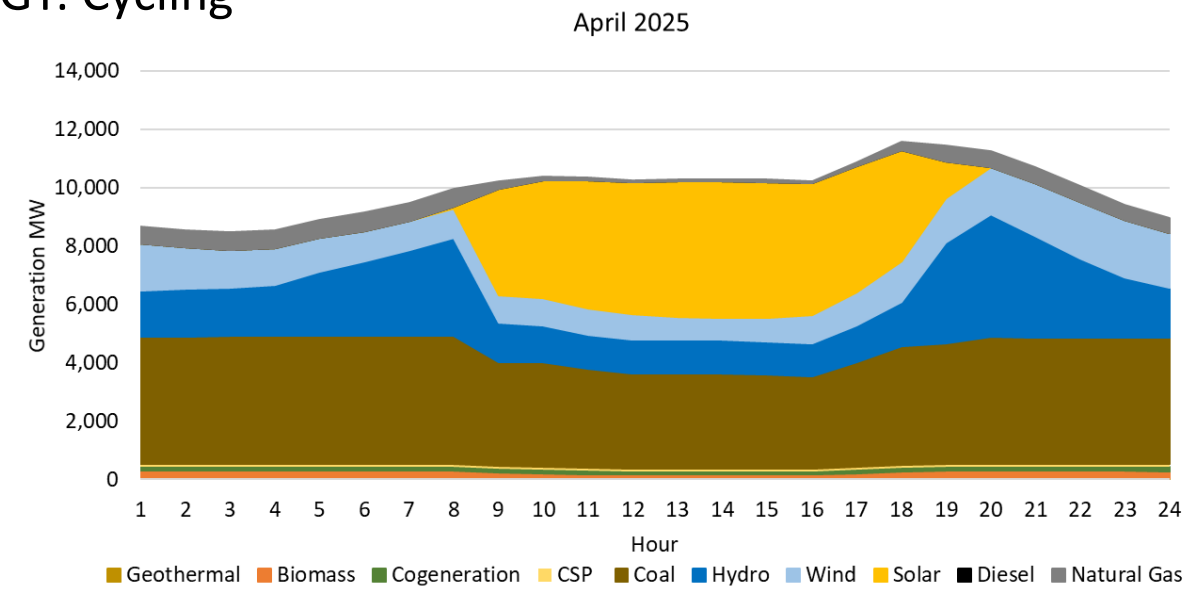

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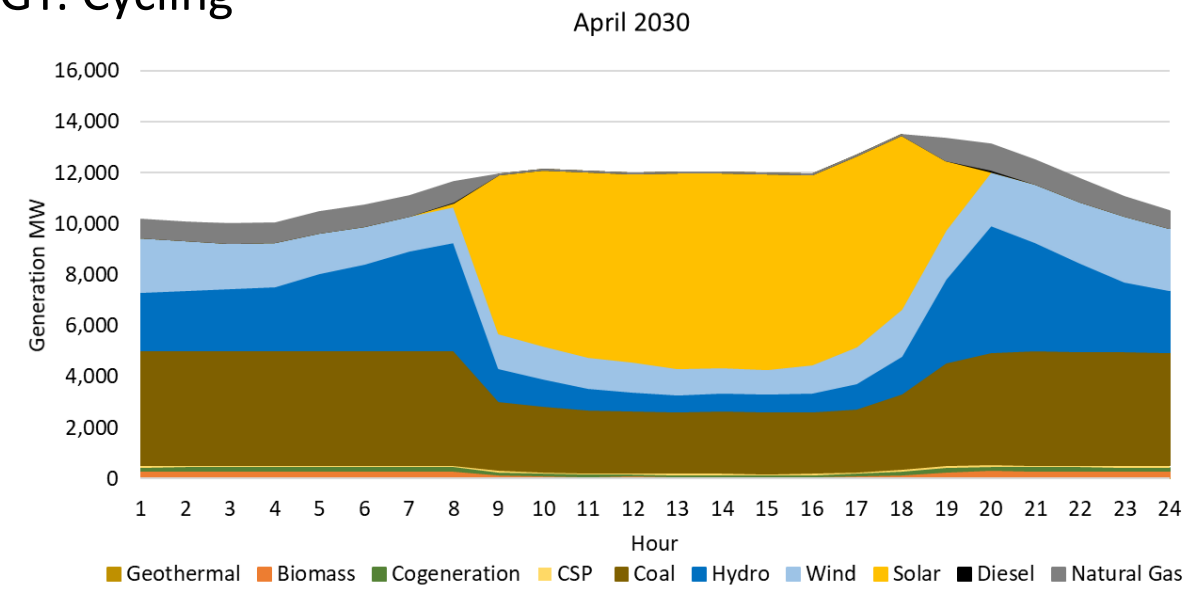
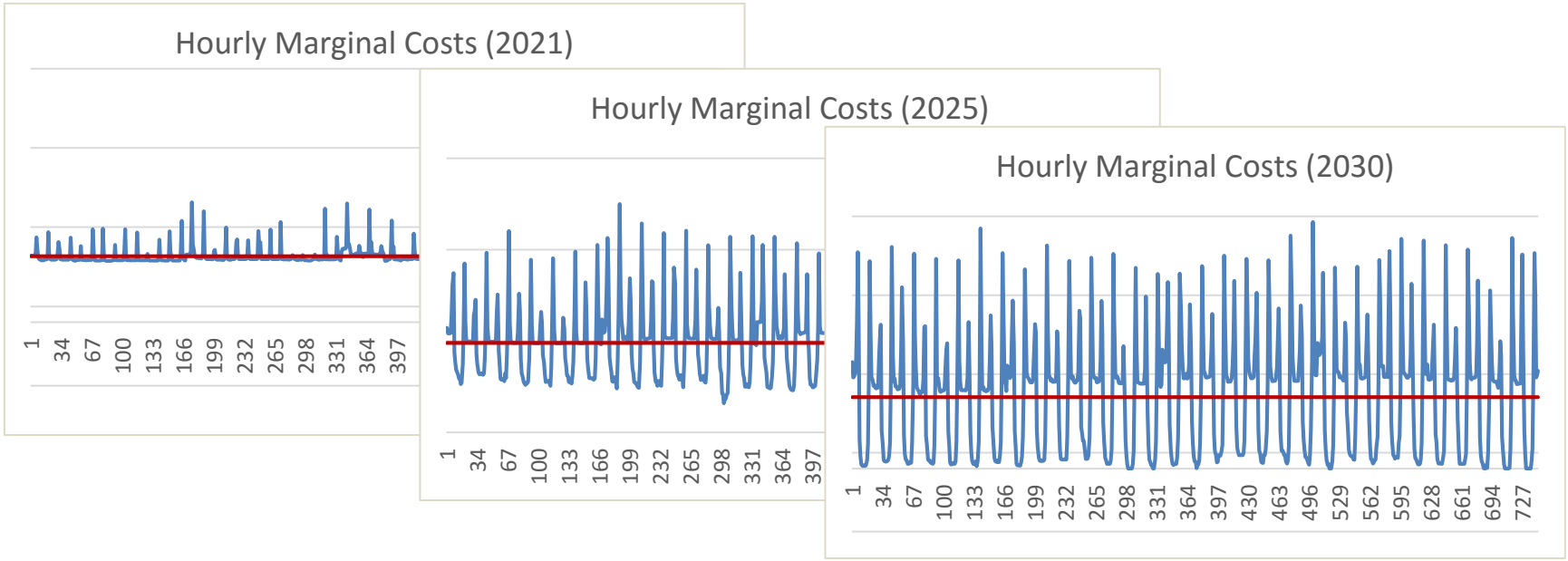


Note: Median Hydrology - DMCM

Main Results: Marginal Cost

- Fluctuation of intraday marginal cost increases over time leading to potential collapse during solar hours by 2030

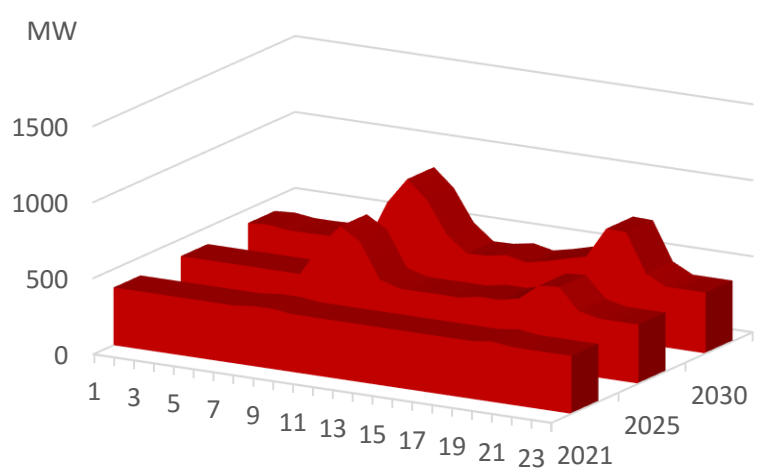


- The minimum cost expansion requires long-term signals (contracts)
  - Pure short-term marginal cost signals (in solar hours) may be insufficient to trigger investment

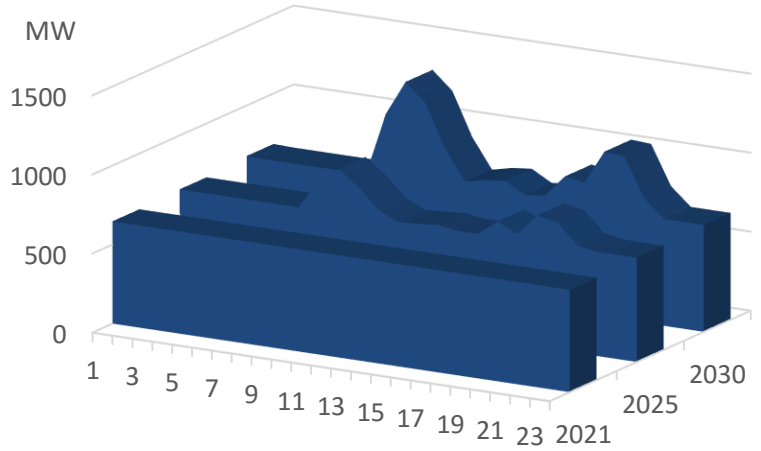
Main Results: Reserve Requirements

- Increasing reserve requirements in certain periods of the day
- Dynamic probabilistic reserve determination criteria will be key to address high VRE insertion levels

Minimum Reserve SING (DACB)

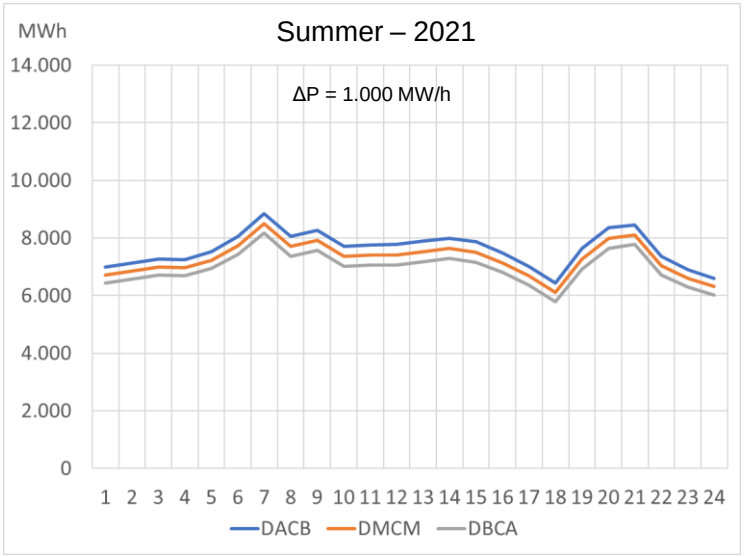


Minimum Reserve SIC (DACB)

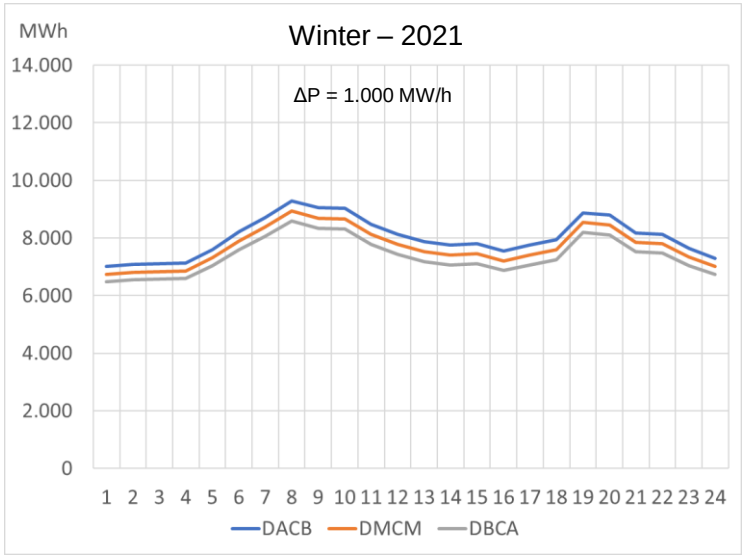


Main Results: Flexibility – 2021

- Residual generation[1]: the Chilean 'Duck Curve'



Case	Max Increase		Max Distribution	
	MW/min	Between Hours	MW/min	Between Hours
DACB	19,8	18-19	-18,2	21-22
DMCM	19,3	18-19	-17,8	21-22
DBCA	18,8	18-19	-17,4	21-22

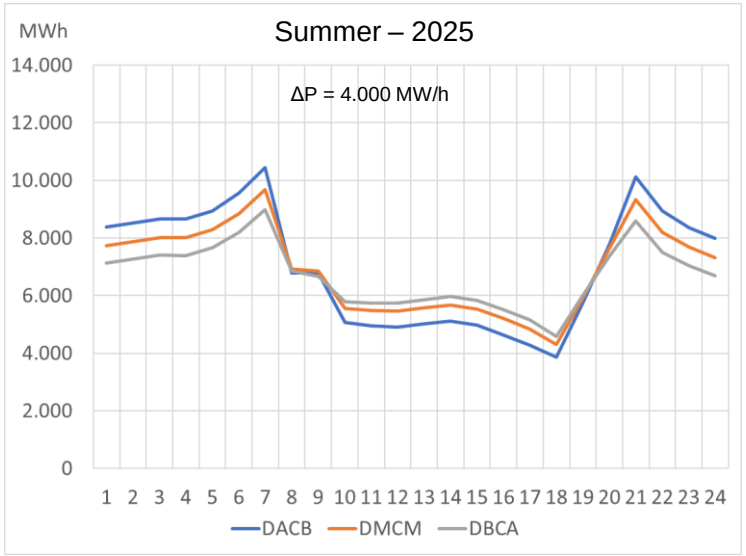


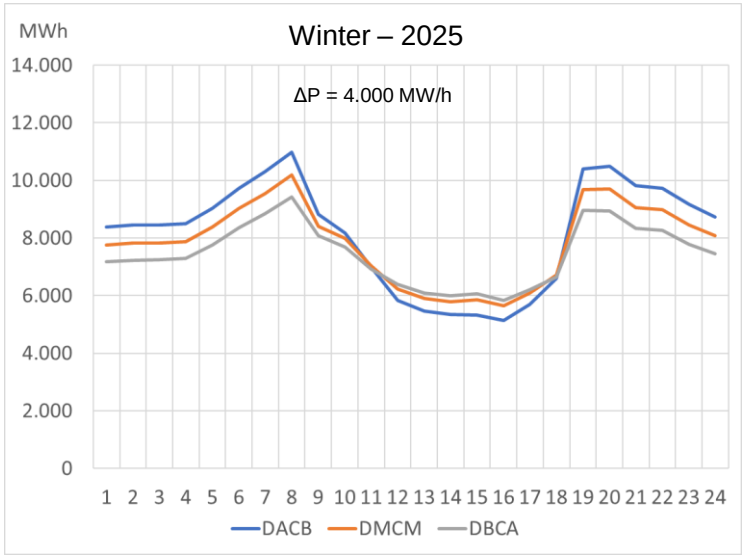
Case	Max Increase		Max Distribution	
	MW/min	Between Hours	MW/min	Between Hours
DACB	15,7	18-19	-10,1	20-21
DMCM	15,8	18-19	-9,9	20-21
DBCA	15,9	18-19	-9,7	20-21

Note: (1) Discounting VRE generation. Median Hydrology - DMCM

Main Results: Flexibility – 2025

- Residual generation[1]: the Chilean 'Duck Curve'





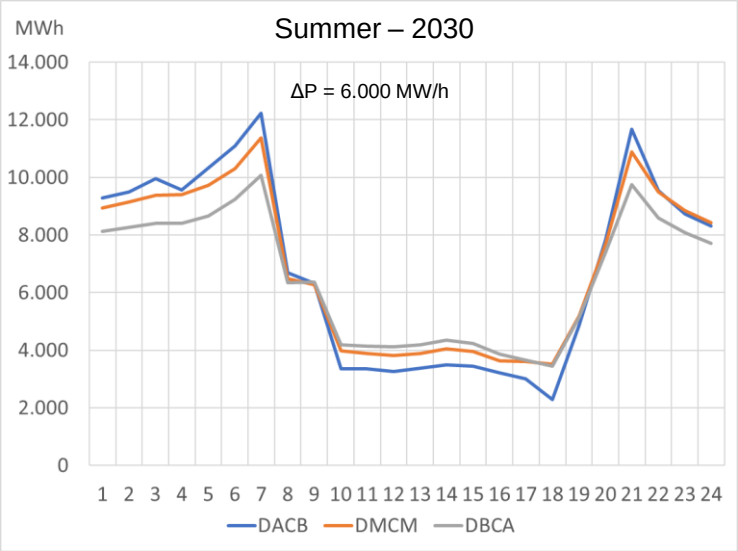
Case	Max Increase		Max Distribution	
	MW/min	Between Hours	MW/min	Between Hours
DACB	38,7	20-21	-61,2	7-8
DMCM	29,0	19-20	-46,3	7-8
DBCA	23,9	18-19	-35,4	7-8

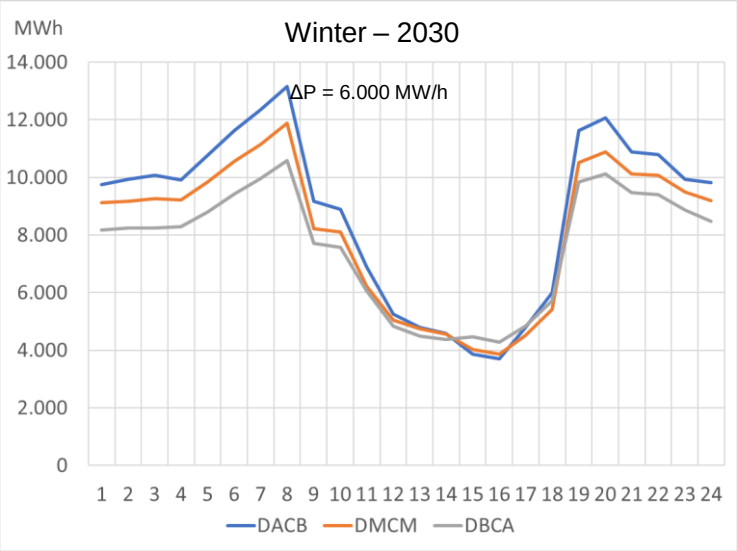
Case	Max Increase		Max Distribution	
	MW/min	Between Hours	MW/min	Between Hours
DACB	63,2	18-19	-36,0	8-9
DMCM	49,6	18-19	-29,6	8-9
DBCA	38,7	18-19	-22,4	8-9

Note: (1) Discounting VRE generation. Median Hydrology - DMCM

Main Results: Flexibility – 2030

- Residual generation[1]: the Chilean 'Duck Curve'





Case	Max Increase		Max Distribution	
	MW/min	Between Hours	MW/min	Between Hours
DACB	63,7	20-21	-92,6	7-8
DMCM	53,0	20-21	-81,5	7-8
DBCA	39,1	20-21	-62,3	7-8

Case	Max Increase		Max Distribution	
	MW/min	Between Hours	MW/min	Between Hours
DACB	94,0	18-19	-66,3	8-9
DMCM	84,9	18-19	-60,8	8-9
DBCA	68,7	18-19	-47,9	8-9

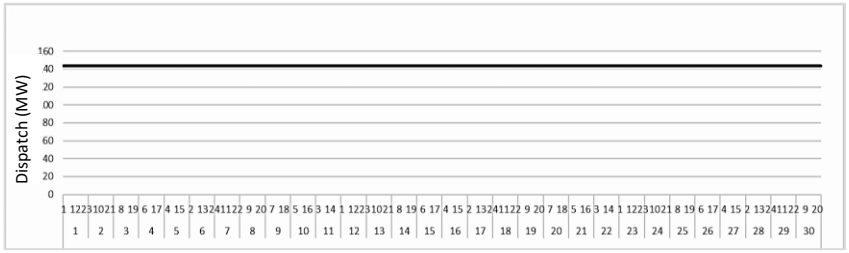
Note: (1) Discounting VRE generation. Median Hydrology - DMCM

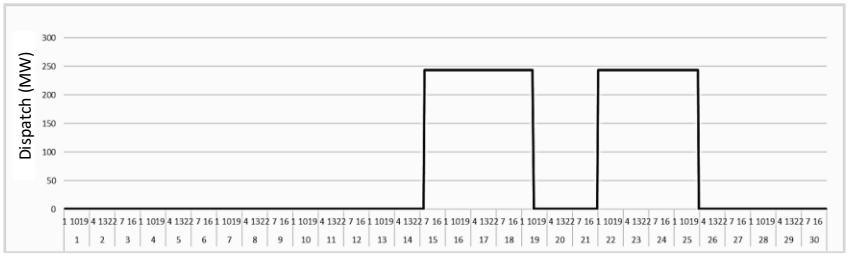
Main Results: Thermoelectricty Cycling

Coal Plant:

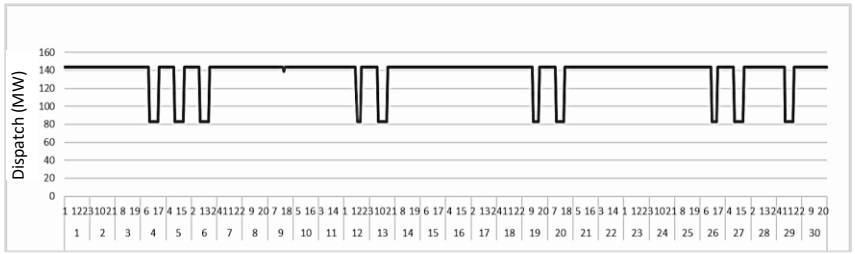
CCGT:

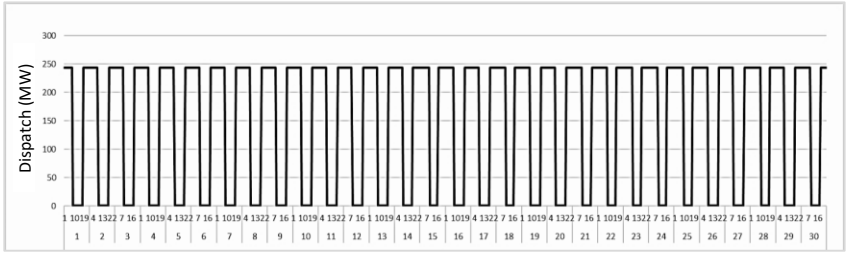
2021



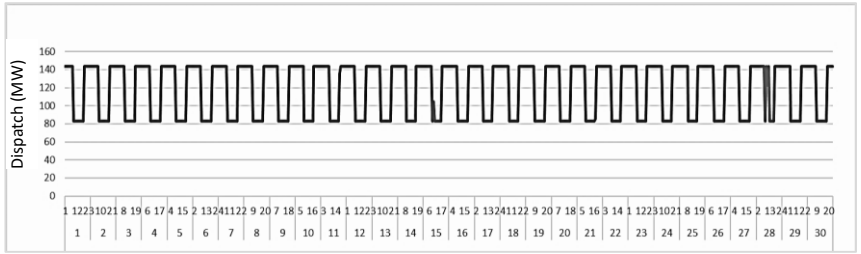


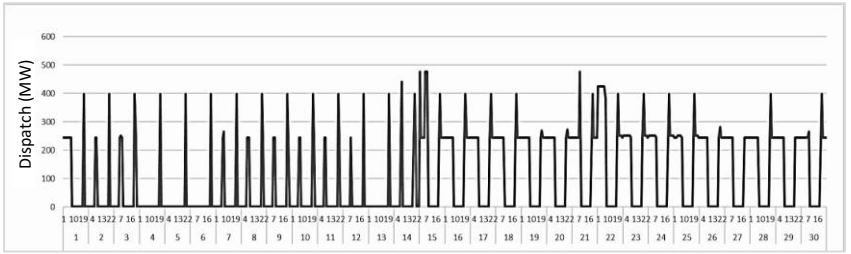
2025





2030

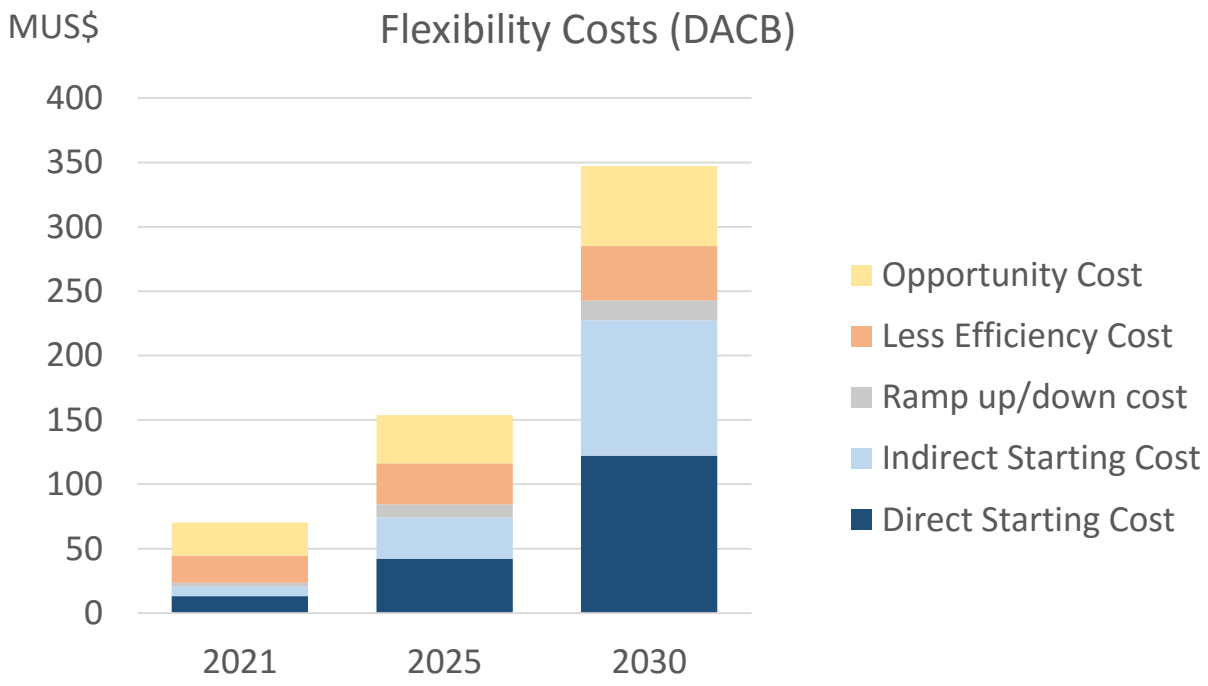




Note: Results corresponds to April, DMCM scenario.

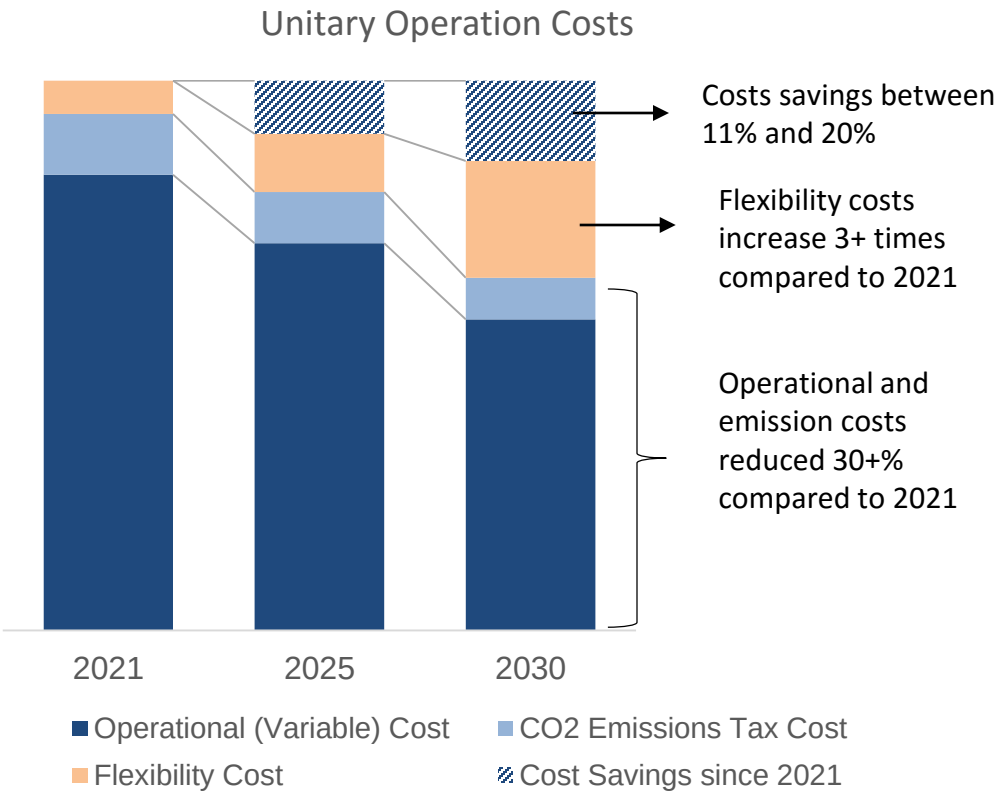
Main Results: Flexibility Costs

- Thermoelectric generators will incur in increasing flexibility costs
  - US$150 to 350 millions per year in 2030 (mostly driven by start up/down cycles)



Conclusions

- Unitary operation costs will be reduced between 11% and 20% by 2030
- Flexibility costs could reach up to US $ 350 millions by 2030



- Flexibility costs must be addressed in the regulation so that the potential VRE expansion can be achieved in an efficient manner

Further reading

- Full report and additional presentations can be downloaded from our website:

http://www.morayenergy.com/

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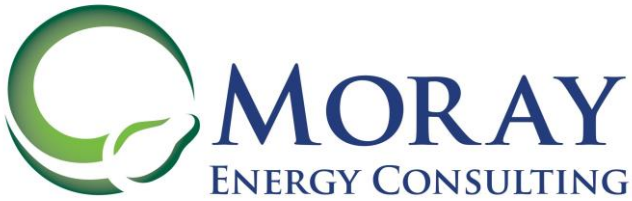

Disruptive factors

- The analysis presented is subject to the following uncertainty factors:
  - Changes in the CO_2 tax level and treatment
  - Corporate decarbonization policies
  - Effect of climate change on hydrology
  - Greater competitiveness of storage systems
  - International interconnections development (electricity and gas)